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Total Evaporative Resistance of Selected Clothing Ensembles

by

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of the requirements for the degree of
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Total Evaporative Resistance of Selected Clothing Ensembles

Victor Caravello

ABSTRACT

With regard to heat stress, the limiting factor inherent in clothing ensembles is the total evaporative resistance. For the same work demands, clothing with higher evaporative resistance impedes the ability to cool by sweat evaporation. Knowing the evaporative resistance provides a means to compare candidate ensembles. Further, a value for evaporative resistance means that a rational method can be used to assess the heat stress exposure. Evaporative resistance of five clothing ensembles (cotton work clothes, cotton coveralls, and three coveralls of particle barrier, liquid barrier and vapor barrier properties) was determined empirically from wear tests during two study phases. For Phase 1, the metabolic rate was held constant at 160 W/m^2, and three levels of humidity (20, 50, 70% rh) were explored. Fourteen heat-acclimated participants (9 men and 5 women) completed trials for all combinations of clothing ensemble and environment. In the Phase 2 study, the humidity was held constant at 50% rh, and three levels of metabolic rate (114, 176, 250 W/m^2) were explored. Fifteen heat-acclimated participants (11 men and 4 women) completed trials for all combinations of clothing ensemble and environment. The data from both phases were analyzed separately using ANOVA. Significant differences were found among ensembles ($p<0.0001$). The vapor barrier ensemble had the highest resistance at 0.026 kPa m^2/W. The liquid barrier was

next at 0.018; followed by the particle barrier and cotton coveralls at 0.016. Work clothes was 0.014 kPa m^2/W. Pair-wise comparisons adjusted for multiple comparisons were used to locate the differences among ensembles. Vapor and liquid barrier ensembles were found to be significantly different from other ensembles. Data from both studies support the conclusion that there are differences in evaporative resistances among selected ensembles tested. From the Phase 2 study, Ensembles B – E evaporative resistances decreased from 0.0024 to 0.0094 kPa m^2/W with increased activity. The decreased evaporative resistances in Phase 2 can be explained by the pumping action associated with increased work. The relationship of $R_{e,T}$ to the difference of $P_{air} - P_{skin}$ (ΔP) was explored and found $R_{e,T}$ does not remain constant. Environment appeared to have greater influence on this relationship.

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INTRODUCTION

Personal protective clothing has become commonplace in many industries today. While protective clothing provides protection from exposure to chemical and physical agents, it may lead to another health issue – excessive heat strain. Heat strain, the physiological adjustment to heat stress, is driven by work demand, environmental factors (such as ambient temperature, relative humidity and air movement), and clothing requirements. Heat strain is marked by increased body temperature, heart rate and sweating. Heat stress has been studied extensively, and one of the critical factors that ties protective clothing to heat stress is evaporative resistance.

Heat Exchange

To better understand the role of clothing in heat stress, the workplace factors discussed above can be described through a thermal balance model. This model balances net heat gained by the body with the required heat loss to prevent excessive heat buildup; that is, to maintain thermal equilibrium. Thermal balance is frequently described by some variation of Equation 1 [1, 2].

$$S = (M - W) + R + C - E \tag{1}$$

The heat storage rate (S) represents the net heat gain to or loss from the body. By convention, body temperature increases when S is positive and decreases when heat is lost (S is negative). When S = 0, the body is considered to be in thermal equilibrium. Heat is generated internally by metabolism (M). The rate of metabolic heat gain is determined by the rate and type of external work performed by the body. The total heat generated by metabolic demands from the work is equal to metabolic rate less the rate of external work performed (W). The rate of radiant heat transfer (R) between the skin and the environment and the rate of heat transfer between the air and skin surface (C) collectively characterize dry heat exchange. Positive values for R + C are a heat gain while negative values indicate a heat loss. The term E represents the rate of evaporative cooling due to the evaporation of sweat, which is the primary mechanism for cooling the body.

Heat production is determined by the amount of metabolic activity. At rest, the body generates heat from the energy produced to maintain basic body functions such as respiration and heart rate to supply the needed oxygen and nutrients to the cells. Metabolic activity rises as one becomes more active. This rise results with higher demand for oxygen and nutrients accompanied by increased metabolism at the active muscles. With increased metabolism, there is increased heat production in the muscle. The greater the demand, the more internal heat is generated. With the understanding that

R + C have a lesser effect of increasing internal heat production, the fundamental link between metabolic rate (work demands) to heat storage becomes clear [3].

The minimal effect of dry heat exchange (R + C) as compared to the other terms in Equation 1 becomes evident as these terms are examined closer. Looking first at heat transfer rate by convection (C), as ambient air temperature is raised above skin temperature, the rate of heat gain by convection is increased. Simply stated, C is the difference of the ambient air temperature and the average skin temperature and modified by the rate of air movement over the skin. If the ambient air is cooler than the skin, then heat flows away from the body. The rate and direction of convective heat exchange depends on the temperature gradient between the air and the skin. The rate, but not direction, is also influenced by air motion and clothing. Generally the higher the air motion or velocity, the greater the rate of heat transfer. Clothing provides a barrier to the heat transfer through its insulation, so the more skin that is covered and/or the thicker the clothing, the lower the rate of convective heat transfer.

The temperature of surrounding objects affects the radiant heat exchange between the environment and the body. Surfaces of different temperatures have a net heat flow from the hotter to the cooler surface by thermal radiation. The rate of heat transfer by radiant heat (R) depends on two factors. The first is the temperature gradient between the skin and surrounding objects. If the average temperature of surrounding objects is greater than skin temperature, there is a heat gain. Conversely, if the surroundings have a

lower average temperature than the skin, a heat loss occurs. The rate of heat transfer is proportional to the temperature gradient. The second factor is clothing insulation. As with convection, the thicker the clothing and/or the more skin that is covered, the lower the rate of heat transfer. Also, if the clothing has a reflective surface, the thermal radiation (or heat) is reflected away. Once the environmental temperature exceeds 35°F the body can dissipate heat only by evaporation [2].

Evaporation of sweat from the skin is the primary mechanism for losing excess body heat during activity. However, there is a limit to the amount of evaporative cooling that can occur. This limit is due to two factors; a physiological and a physical limit. The physiological limit is the amount of sweat that can be produced over time. The physical limit is the maximum rate of evaporative cooling (E_{max}) that can occur. E_{max} is limited by three primary factors. First, evaporation can only occur if the water vapor pressure of the skin (P_{sk}) is higher than the water vapor pressure of the ambient air (P_a). Humidity is the ambient water vapor pressure. As humidity increases, this gradient from skin to air is reduced, and the rate of evaporative heat loss is decreased. The second factor is air movement. As air velocity increases, the boundary layer between the person and environment decreases allowing for an increase in evaporation of sweat (E_{max} increases). The third factor is clothing. All clothing acts as a barrier to evaporation. The physical characteristic known as the water vapor permeability of the clothing is directly proportional to the ability to evaporate sweat (E_{max}). Therefore, as the water vapor permeability decreases, so does E_{max}.

Air velocity, generated by body movements and air movement, is important in heat exchange between the body and the environment because of its role in convective and evaporative heat transfer. Increasing the air velocity can increase the convective and evaporative heat exchange by forcing air between the clothing and skin.

Role of Clothing in Heat Balance

Clothing impedes heat exchange between the body and the environment by limiting dry heat exchange and evaporative cooling. These effects can be described in further detail by looking at three characteristics associated with clothing: insulation, permeability and ventilation [4].

Insulation

Insulation describes the resistance to heat flow by convection and radiation. With the environmental conditions being constant, the gradient between the skin and air remains the same, but the as the insulation for an ensemble increases, the heat flow due to radiation and convection decreases. In other words, dry heat exchange through the clothing decreases with increasing insulation.

Permeability

Permeability is the ability of water vapor to move through clothing. It affects the amount of evaporative cooling that can occur. Clothing with low permeability indicates that evaporation of sweat through the clothing is reduced, resulting in a decrease in evaporative cooling. Protective clothing ensembles can vary over a range from easily permeable to essentially impermeable.

Ventilation

Ventilation occurs as ambient air moves through the fabric and/or through clothing openings (cuffs, fasteners, and collar). Clothing that allows air movement increases convective and evaporative cooling. Conversely, if the clothing is designed to limit the movement of air by being encapsulating or tight fitting with elastic cuffs, the convective and evaporative cooling are limited.

Although protective clothing ensembles are worn to protect workers from biological, chemical or physical hazards, the barrier posses another hazard to workers by reducing the wearer's ability to dissipate internally generated heat through sweat evaporation. Depending on the environment and work demands, an excessive level of heat stress may result. Heat stress may cause reduced performance and increased risk of accidents and heat injury. It is imperative to understand the clothing characteristics, with the evaporative resistance being the most important, in order to effective manage the risks associated with wearing the protective clothing.

LITERATURE REVIEW

Protective clothing and environmental conditions influence the level of heat stress a worker may experience. Understanding fabric properties may help predict how the environment will affect heat transfer for a selected ensemble. Havenith points out the importance of heat balance when wearing protective clothing [4]. The goal is to maintain the body at around 37°C by transferring excess heat from the body to the environment. Heat is produced through metabolic activity and protective clothing may hinder the loss of the heat gained. Some important factors that affect heat transfer from the body to the environment include the temperature (air, surface, radiant), humidity, wind, movement, and clothing insulation [4]. While all of these factors can affect heat transfer, the primary mechanism the body uses to dissipate heat is evaporative cooling. Therefore it is important to understand the potential barrier an ensemble may pose to evaporation of sweat. As sweat is secreted onto the skin, it should evaporate and cool the body. The rate of evaporation depends on the difference between the water vapor pressure of the skin and the ambient air water vapor pressure as well as the barrier provided by the clothing. This barrier interferes with the ability of water vapor to pass from the skin through the ensemble and into the ambient air. Therefore it is important to be able to

distinguish between clothing ensembles in terms of their permeability to water vapor. Permeability is alternatively expressed as total evaporative resistance ($R_{e,T}$).

In addition to evaporative cooling, heat loss from the skin to the ambient air occurs by radiation and convection (dry heat exchange). Dry heat exchange occurs because of the temperature difference between the skin and surrounding air. As with evaporation of water, dry heat also must leave the skin and be transported into and out of the clothing before the heat loss is complete. Therefore, clothing may interfere with dry heat exchange. This characteristic of clothing is referred to as insulation.

The total clothing insulation (I_T) and the total evaporative resistance ($R_{e,T}$) are important characteristics to consider when comparing clothing ensembles. I_T is an attribute that accounts for a decrease in heat flow due to total insulation provided by the clothing and the air layer between the skin and clothing. The higher the value of I_T, the lower net heat flow due to radiation and convection is achieved. $R_{e,T}$ is the clothing characteristic that accounts for water vapor flow due to clothing permeability. The higher the value of evaporative resistance, the less evaporative cooling occurs; hence, the higher the level of heat stress. Although I_T is associated with $R_{e,T}$, the relationship is neither linear nor fixed for all clothing.

To complicate matters, dry heat exchange and evaporative cooling are altered with air and body movement. Consequently, as work demands increase, it is possible to

see a decrease in the total evaporative resistance and I_T. Both terms have static and dynamic values associated with its use. That is $I_{T,stat}$ is associated with the total insulation of clothing absent of movement, and $I_{T,dyn}$ is associated with the total insulation of clothing with movement. The same associations are true for $R_{e,T}$. Thus, it is important to understand the thermal resistance properties of ensembles and how environment and activity level alters them.

Components of Insulation and Evaporative Resistance

In 1955 Burton and Edholm introduced the new unit for clothing insulation – the clo. One clo of insulation was intended to be equivalent to thermal insulation required to keep a sedentary person comfortable with normal indoor clothing at normal indoor climatic conditions (21°C). The purpose of using the unit clo was to remove the awkward physical unit of m^2 °C/W, so one clo equals 0.155 m^2 °C/W [5]. Goldman points out the advantage of using the clo as the unit of insulation is that it can be expressed as heat loss that will occur for the average adult male who has 1.8 m^2 of surface area, using a simple relationship that such an individual will lose 10 kcal/hr of heat by radiation and convection for every degree (°C) difference between the average skin temperature and the air temperature with 1 clo unit of insulation [6]. Therefore 5 kcal/hr will be lost with 2 clo units of insulation.

Total clothing insulation (I_T) is the combined insulation provided by clothing and the surrounding layer of air. Parsons [7] describes this relationship mathematically as:

$$I_T = I_{cl} + I_a \tag{2}$$

Intrinsic clothing insulation (I_{cl}) is a characteristic of the clothing itself and not the external environment or the body condition. I_{cl} represents the resistance to heat transfer between the clothing surface and the skin. Typical units are °C m^2/W. I_{cl} values and clo units are still used in several thermal comfort and clothing standards and information on determining I_{cl} from measured values of I_T is described in ISO Standard 9920 [7, 8].

I_a describes the thermal resistance or insulation provided by the air between the skin and garment. The properties of this layer are important to heat exchange and can be affected by the external environmental conditions.

For an individual wearing an ensemble, the surface area of the individual is increased by an amount related to the thickness of the clothing layer. This new surface area is difficult to determine, but is important for other relationships with heat transfer. A clothing adjustment factor (f_{cl}) is used to account for this new surface area. The term f_{cl} is the ratio of the clothed surface area of the body to the nude surface area of the body.

The following equation is an approximation for f_{cl} given by McCullough and Jones (1984) [7].

$$f_{cl} = 1.0 + 0.31\ I_{cl}\ (\text{clo}) \tag{3}$$

To determine the intrinsic clothing insulation, $I_{T,stat}$ is measured using a clothed manikin or hot plate as described in the following section. I_a is measured in a similar fashion, but without the fabric sample or clothing. Then,

$$I_{cl} = I_{T,stat} - I_a/f_{cl} \tag{4}$$

A more convenient term for measurement is effective clothing insulation (I_{cle}), which is an approximation for I_{cl} for the test conditions. This is described by the following equation:

$$I_{cle} = I_T - I_a \tag{5}$$

This same principle can be applied for the total evaporative resistance of clothing ($R_{e,T}$) by dividing it into two components. The evaporative resistance due to the clothing itself (R_{cl}) and that due to the air layer (R_a) near the clothing or exposed skin.

$$R_{e,T} = R_{cl} + R_a \tag{6}$$

Values for $R_{e,T}$ and R_a can be determined empirically from variations of the standard tests for clothing insulation using sweating hot plates or sweating manikins (see next section). In this way, R_{cl} can be estimated from the following equation.

$$R_{cl} = R_{e,T} - R_a / f_{cl} \qquad (7)$$

Again, a convenient approximation is

$$R_{cle} = R_{e,T} - R_a \qquad (8)$$

Laboratory Test Methods

There are three different methods for determining the thermal properties of a garment. The first method involves the use of a heated plate; the second involves a heated copper manikin; and the third method involves the use of human participants.

Hot Plate Method

While manikins and hotplates use similar basic principles to determine heat loss and insulation values, they typically have different end goals. A hotplate is designed to provide accurate one-dimensional heat and moisture flow through a fabric sample to

determine thermal and water vapor resistance. The goal is to accurately evaluate the material properties for the test environment only [9].

The American Society for Testing and Materials (ASTM) developed a standard method for using a sweating hot plate in method F 1868-02 [10]. This test method covers the measurement of the thermal resistance and the evaporative resistance under steady-state conditions of fabrics, films, coatings, foams, and leathers, including multi-layer assemblies, for use in clothing systems. There are several relevant measures from sweating hot plate tests. The most basic measure is the operating heat flux required to maintain a constant skin temperature. In dry tests, it represents the conductive/ convective/radiative heat transfer. In sweating tests, it also includes evaporative heat losses. This sweating test is the most common method used.

Copper Manikin

A life-sized heated copper manikin can be used in the evaluation of the heat transfer potential of clothing garments. Similar to the hot plate method, the manikin is electrically heated so that the skin temperature is similar to that of people. Depending on number of surface segments the resolution can be adjusted to be sufficiently high to complete the measurement task. Some manikins in use today have 1 zone while others have more than 100 individually regulated segments. By summing up the area weighted heat loss values from the manikin, a total value for whole body heat loss is determined.

Some performance features of the most commonly used thermal manikins are: simulation of human body heat exchange, measurement of 3-dimensional heat exchange, integration of dry heat losses, measurement of clothing thermal insulation, product development, and providing values for prediction models.

Values obtained with different manikins in different laboratories should be comparable and similar within defined limits for the same test conditions. The conditions and requirements for comparable measurements with different manikins and methods are defined in standards. The American Society for Testing and Materials standardized this procedure in ASTM method F 1291-99, and the International Organization for Standardization standardized the procedures in ISO 9920 [11, 12]. ASTM method F 1291 and ISO 9920 are both in the process of being updated to reflect the changes with the new sweating manikin. Similar to the hot plate procedures, these test methods cover the measurement of the thermal resistance and the evaporative resistance under steady-state conditions. With over a hundred different manikins being built and used around the world, it is difficult for any standard to encompass procedures for all types of manikins.

Thermal manikins have evolved from its first model in 1941 for testing military clothing, and can be grouped into three categories. First are static (non-moving) and non-perspiring units, second are movable (walkable), but non-perspiring ones such as the copper manikin 'Charlie' in Germany used by Mecheels and Umbach in 1977, and third

are sweating manikins [13]. To simulate sweating on non-perspiring manikins, many researchers used highly absorbent fabrics on the manikin (under the tested garment) and supplied water to the "underwear" by sprinkling or water pipes. The third generation manikins simulate true perspiration and body motion, but again not all sweating manikins are dynamic.

Recent innovation at the Institute of Textiles and Clothing, Hong Kong, produced Walter the "sweating" manikin. Walter is made up of water, mechatronics and breathable fabric, allowing realistic simulation of human thermal physiology under various environments. Walter has waterproof but moisture-permeable fabric skin, which can be unzipped, removed and interchanged with different skins, simulating different rates and patterns of perspiration. In addition, Walter is a dynamic manikin that allows researchers to simulate the process of walking. This new technology surprisingly has an affordable price tag associated with it as it may be 90% less than traditional copper and plastic manikins [14].

Human Tests for Clothing Thermal Characteristics

Though useful, measurements of clothing thermal properties made on hot plates or manikins do not represent the properties of clothing during wear. The movements of the worker increase the convective air flow both between layers and at the clothing surface, modifying both insulation and vapor permeability. Although recent

developments with dynamic sweating manikins provide accurate data on clothing insulation and evaporative resistance, there still exists a difference between manikin and human wear tests.

Human wear testing to determine evaporative resistance and clothing insulation values are based on determining the "prescriptive zone" as described by Lind [15]. The upper limit prescriptive zone was defined as the point where heat loss and heat gain were equal ($E_{max} = E_{req}$).

Using the premise of the prescriptive zone, Belding and Kamon proposed a method for determining ambient vapor pressures at 36°C for a variety of exercise intensities and air movements [16]. Their method used a time-intensive protocol to determine critical environmental conditions for evaporative heat loss. Kamon and Avellini used the same approach as Belding and Kamon [17]. In their experiments, the participants were subjected to a range of ambient temperatures between 36 and 52°C with the water vapor pressure progressively increased at each ambient temperature. It was expected that on the basis of the body core temperature inflection, a line for the safe limit for the psychrometric chart would be empirically identified particularly for the higher temperatures, where individual sweating rate capacity was believed to be the limiting factor. Holmer and Elnas developed a method to determine both the evaporative and sensible heat loss occurring simultaneously [18]. However, this method was difficult because direct measurement of the water vapor pressure gradient between the skin and

ambient air was required. Kenney et al. simplified this procedure by minimizing the number and duration of tests necessary to determine these limits [19]. However, these more time-efficient protocols require the ability to systematically change ambient temperature or water vapor pressure.

In the Kenney method, the metabolic rate target was 30% of maximal aerobic capacity (MAC). Generally, a person can work at 1/3 their MAC for an 8-hour work day [20].

The testing chamber was controlled in that the dry bulb temperature (T_{db}) and wet bulb temperature (T_{wb}) could be closely manipulated. Air velocity was 0.5 m/s or less. The participant's heart rate (HR), rectal temperature (T_{re}) and mean skin temperature (T_{sk}) were monitored.

Each participant partook in two trials wearing the garment to be tested. In one of the trials, T_{db} was held constant and after 30 minutes for stabilization, the ambient water vapor pressure (P_a) was increased in increments of 0.13 kPa every 5 minutes. In the other trial, the P_a was held constant at a low humidity while the T_{db} was increased in 1°C increments every five minutes.

The T_{re} for each participant was plotted and the point of inflection where T_{re} sharply rose was noted. This inflection point represented the inability of the body to

dissipate the heat load and thereafter heat was stored by the body. Data from a participant was plotted, as shown in Figure 1, to illustrate the typical time course for an inflection point protocol. The important points of this figure is the starting T_{re} with a steady rise until a steady state is achieved, and then the inflection point followed by steep rise in T_{re}. Using this method, the critical temperature (T_{crit}) at a given P_a and the critical water vapor pressure (P_{crit}) at a given T_{db} can be determined.

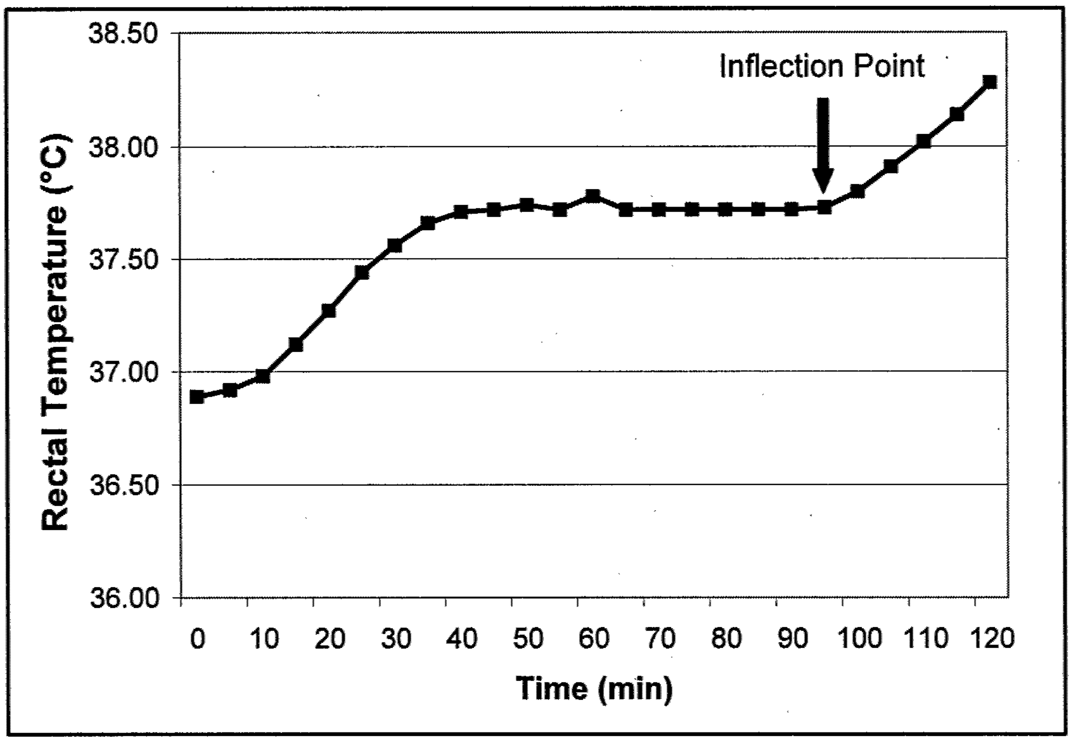


Figure 1. Typical Time Course for T_{re} During an Inflection Point Protocol.

At the inflection point, the required rate of evaporative cooling (E_{req}) was equal to the maximum rate of evaporation (E_{max}). In other words, the rate of heat storage was zero

since the evaporative cooling was equal to the net heat gain from metabolism plus the dry heat exchange.

$$E_{max} = (M_{net}) + (R+C) \tag{9}$$

Another condition that existed at the inflection point was that evaporative cooling was at its maximum value. Here evaporative cooling (E_{max}) was equal to the difference in water vapor pressure between the skin (P_{sk}) and the ambient environment (P_a) divided by the total evaporative resistance ($R_{e,T}$). This is shown in the following equation:

$$E_{max} = (P_{sk}-P_a)/R_{e,T} \tag{10}$$

The relationship of $R_{e,T}$ with respect to ΔP ($P_{sk} - P_a$) and E_{max} is based on the assumption that $R_{e,T}$ remains the same as ΔP and E_{max} change. However, there are some researchers that question this principle. In his paper, Bernard found that a warm humid environment resulted with a lower $R_{e,T}$ [30]. Theoretically, the maximum sweat rate is proportional to the difference in the saturated partial pressure of water at the skin minus the partial pressure in the air, and the evaporative resistance of clothing worn has no effect. The question about $R_{e,T}$ being a constant, as accepted in Equation 10, regardless of environment has not been evaluated.

Without a direct source of radiant heat, the rate of dry heat exchange (R+C) was taken as the difference in T_{db} and T_{sk} divided by the clothing insulation (I_T). This is presented in the following equation:

$$(R+C) = (T_{db}-T_{sk})/I_T \tag{11}$$

By substituting Equations 10 and 11 into Equation 9, the following equation results.

$$(P_{sk}-P_a)/R_{e,T} = (M_{net})+(T_{db}-T_{sk})/I_T \tag{12}$$

When the measured values and environmental conditions were placed in Equation 12 for each of two inflection points, there were two equations with two unknowns. This allowed for the calculation of I_T and $R_{e,T}$.

At each inflection point, heat gain equals heat loss. This is represented mathematically using the following equation:

$$M_{net} + (R + C) = E, \tag{13}$$

where M_{net} is the net metabolic heat production (M) corrected for external work (W) and respiratory exchanges due to convection (C_{res}) and evaporation (E_{res}). Metabolic rate (M)

in W/m^2 was estimated from oxygen consumption in liters per minute and the respiratory ratio (R) using the following equation [21]:

$$M = 352(0.23R + 0.77) \cdot VO_2/A_D \qquad (14)$$

The Dubois surface area (A_D) was calculated for each subject using the following equation [22]:

$$A_D = 0.202 \cdot W^{0.425} \cdot H^{0.725}, \qquad (15)$$

where W was the weight of the body (kg) and H was the height of the body (m).

The external work (W) was calculated (W/m^2) using the following equation:

$$W = -\,0.163 \cdot m_b \cdot V_W \cdot f_g / A_D, \qquad (16)$$

where m_b was body mass in kg, V_W was walking velocity in m/min, f_g was the fractional grade of the treadmill, and A_D was the Dubois surface area.

Respiratory exchanges, latent respiration heat loss (E_{res}) and dry respiration heat loss (C_{res}), were calculated as follows:

$$C_{res} = 0.0012 \cdot M \cdot (34 - T_{db}) \tag{17}$$

and

$$E_{res} = 0.0173 \cdot M \cdot (5.87 - P_{dp}) \tag{18}$$

The net metabolic rate (M_{net}) from Equation 13 can be calculated in W/m^2 using the following equation:

$$M_{net} = (M - W) + C_{res} - E_{res} \tag{19}$$

Kenney et al. recognized that there may be some heat storage represented by a gradual change in T_{re} [21]. To account for this, the rate of change in heat storage can be estimated knowing the specific heat of the body (0.97 W h/°C kg), body weight (BW), and the rate of change of body temperature ($\Delta T_{re} / \Delta t$) before the inflection point was reached [23]. That is,

$$S = 0.97\, BW\, \Delta T_{re} / A_D\, \Delta t \tag{20}$$

Thermal Resistance Values for Various Work Ensembles

By using a hot plate, copper manikin or human subjects, thermal resistance values for garment ensembles can be quantified in terms of total insulation (I_T) and total evaporative resistance ($R_{e,T}$). Experimentally determined values for select work ensembles are presented in Table 1 for comparison purposes.

The I_T and $R_{e,T}$ values reported in Table 1 vary within each garment between the method used. Havenith et al. found that heated manikin results for standing/no wind appear to be on the average 0.15 clo (0.023 °C m^2/W) higher than human subjects results [25].

Table 1. Comparison of Experimentally Determined Thermal Resistance Values.

Ensemble Description	I_T (°C m^2/W)	$R_{e,T}$ (kPa m^2/W)	Reference	Method
Tyvek® Coverall	0.070	0.020	[24]	hot plate
Tyvek® Coverall	0.171	0.033	[24]	manikin
Tyvek® Coverall	0.086	0.017	[23]	human participant
Gore-Tex® Outer-wear	0.054	0.009	[24]	hot plate
Gore-Tex® Outer-wear	0.210	0.032	[24]	manikin
Gore-Tex® Outer-wear	0.130	0.028	[21]	human participant
Cotton, Single Knit	0.079	0.009	[24]	hot plate
Men's Summer Casual (short sleeve)	0.201	0.029	[24]	manikin
Military Fatigues	0.090	0.016	[21]	human participant

The data in Table 1 shows a larger gap (0.52 – 0.72 clo) between human participants and manikin data. Nishi et al. [26] and Vogt et al. [27] support Havenith's findings, but Nielsen at al. [28] and Olesen et al. [29] found the human participant values were 0.22 clo lower than manikin data.

Havenith et al., found that the permeability index (I'_m) changed with wind and movement [30]. In their study, the permeability increased three fold with permeable clothing and six fold with impermeable clothing. Additionally, they found that the total insulation was reduced by 32% and that walking at slower rates yielded smaller gains. Breckenridge and Goldman [31] reported similar findings with an increase in I_m by 123% and a decrease in I_T by 28%.

A few years later, Parsons et al. [32], Holmer et al. [5], and Havenith at al. [33] all find that $I_{T,stat}$ needs to be adjusted for wind and walking. Their findings were adapted in ISO 7933. Havenith et al. reports that a 78% reduction of $R_{e,T}$ with a 50% reduction in I_T can be seen [33] which is similar to the differences seen in Table 1. $I_{T,dyn}$ is converted by multiplying $I_{T,stat}$ by a correction factor (CF_{cl}) as shown in Equations 21 and 22:

$$I_{T,dyn} = CF_{cl} \times I_{T,stat} \qquad (21)$$

and

$$CF_{cl} = e^{\left(0.043 - 0.398V_{ar} + 0.66V_{ar}^2 - 0.378Walksp + 0.094Walksp^2\right)} \tag{22}$$

where V_{ar} is the velocity of the air and Walksp is the walking speed. The speed is calculated based on the metabolic demand (M in W/m^2) and is shown in the equation below:

$$\text{Walksp} = 0.0052\ (M - 58) \tag{23}$$

Another obvious relationship in Table 1 is that the hot plate values are less than the manikin values for both I_T and $R_{e,T}$. There are a few possible reasons for these differences.

First, the values may be lower than manikin data because of the fit or drape of the clothing. Hot plates tend to tested with a tight fit where the manikins and humans use a looser fit. Second, the wetting of the material is likely to alter the values. Manikin values were measured on dry manikins to determine the dry heat exchange while the hot plates were wet. The clothing on human participants was also wet from sweating. Although the hot plate values are not the same as that of the human participants, they are close in two of the garments tested. Wetting of the clothing alters the obtained value by attenuating the resistance [34]. Third, it is difficult to simulate the movements of exercising humans. The presence of body motion aids in the circulation of air through

the clothing and therefore also reduces the resistance. The effects of air and body movement on I_T and $R_{e,T}$ have been well documented [5, 21, 23, 27, and 28]. Although there is agreement of this needed adjustment, manikin data is not always adjusted for air and movement.

The methodology for using human participants in conducting heat stress studies proposed by Kenney et al [19] has been used by Bernard and Matheen [9], Barker et al. [23], Kenney and Zeman [35], and Malcolm et al. [36] as well as other researchers.

Hypothesis

A reasonable evaluation of selected protective clothing garments would be a determination of their heat exchange characteristics. The primary purpose of this paper was to explore the methodology for being able to distinguish between garments based on the total evaporative resistance properties within different environments and work demands. The secondary purpose is to challenge the relationship of $R_{e,T}$ with respect to changes in ΔP and E_{max}. The default assumption is that $R_{e,T}$ remains the same as ΔP and E_{max} change.

There are three null hypothesis to be tested: (1) there are no differences between mean $R_{e,T}$ values among ensembles, (2) there are no differences between mean $R_{e,T}$ values among environments and metabolic rates/demands, and (3) there are no differences

between mean $R_{e,T}$ values while ΔP changes within environments and metabolic demands.

METHODS

The primary purpose of this paper was to explore the methodology for distinguishing between garments based on the total evaporative resistance properties within different environments and work demands. The secondary purpose is to challenge the relationship of $R_{e,T}$ with respect to changes in ΔP and E_{max}. Experimental trials were conducted to determine the evaporative resistance for five clothing ensembles. The protocols included a fixed metabolic demand under three different relative humidity levels for Phase 1, and for three metabolic demands with a fixed relative humidity level for Phase 2. The key to these studies was being able to distinguish the point of transition from compensable heat stress to uncompensable heat stress ($E_{req} = E_{max}$).

Participants

Fourteen adults (nine men and five women) participated in experimental trials for Phase 1 and fifteen adults (eleven men and four women) participated in Phase 2. Their physical characteristics are provided in Appendix A and the average and standard deviation of their physical characteristics by gender are provided in Table 2. Following

the local IRB procedures, a written informed consent was obtained and all subjects were qualified by a physician.

Prior to beginning the experimental trials, participants underwent a 5-day acclimatization period. Acclimatization involved walking on a treadmill at a metabolic rate of approximately 160 W/m^2 in a climatic chamber at 50°C and 20% relative humidity (rh). During acclimation participants wore shorts (and sports bra), socks and shoes.

Table 2. Summary of Participant Characteristics.

Protocol	Gender	Num	Age (yrs)	Height (cm)	Weight (kg)	Surface Area (m2)
Phase 1 Humidity	Men	9	29.2 ± 6.8	183 ± 6.0	97.2 ± 18.5	2.18 ± 0.20
	Women	5	31.8 ± 9.1	161 ± 7.0	63.5 ± 17.2	1.66 ± 0.23
	All	14	30.1 ± 7.5	175 ± 12.0	85.2 ± 24.1	2.00 ± 0.33
Phase 2 Metabolic	Men	11	28.0 ± 9.5	176 ± 11.2	81.9 ± 11.7	1.98 ± 0.18
	Women	4	23.0 ± 4.7	165 ± 6.3	64.2 ± 18.0	1.70 ± 0.22
	All	15	26.7 ± 8.6	173 ± 11.1	77.2 ± 15.3	1.91 ± 0.22
Both	Men	20	28.6 ± 8.2	180 ± 8.6	89.55 ± 15.1	2.08 ± 0.19
	Women	9	27.4 ± 6.9	163 ± 6.7	63.85 ± 17.6	1.68 ± 0.23
	All	29	28.0 ± 7.5	171 ± 7.6	76.7 ± 16.35	1.88 ± 0.21

Clothing Ensembles

Five different clothing ensembles were evaluated in each Phase with only one ensemble being changed for Phase 2. The ensembles included: Ensemble A -- work clothes (4 oz/yd^2 cotton shirt and 8 oz/yd^2 cotton pants); Ensemble B -- cotton coveralls

($9\text{-}10\ oz/yd^2$) and three limited-use protective clothing ensemble: Ensemble C -- particle-barrier ensembles (Tyvek® 1424 for Phase 1 and Tyvek 1427 for Phase 2), Ensemble D -- water-barrier, vapor-permeable ensembles (NexGen® LS 417), and Ensemble E -- vapor-barrier ensembles (Tychem® QC). The limited-use coveralls had a zippered closure in the front and elastic cuffs at the arms and legs.

All ensembles were worn without a hood and a cotton tee-shirt and/or sports bra and shorts were worn under all clothing ensembles.

Protocols

Three experimental protocols were followed each Phase. The design for Phase 1 had three environments with a fixed metabolic rate. Treadmill speed and grade were set to elicit a metabolic rate of about 160 W/m^2. The first protocol (R7) was a warm/humid environment designed to reduce E_{max} by limiting evaporation. The second protocol (R2) was a hot/dry environment designed to increase E_{req} by increasing radiant and convective (R+C) heat gains. The third protocol (R5) was a moderate environment designed to increase R+C while decreasing E_{max}.

In the R7 protocol, the dry bulb temperature (T_{db}) was set at 30°C and relative humidity (rh) at 70%. Once the participant reached thermal equilibrium (no change in T_{re} and heart rate for at least 15 minutes), T_{db} was increased 0.7°C every 5 minutes. In the

R2 protocol, T_{db} was set at 40°C with rh at 20%. When participants reached thermal equilibrium, T_{db} was increased 1°C every 5 minutes. For the R5 protocol, T_{db} was set at 34°C with 50% rh. Upon reaching thermal equilibrium, T_{db} was increased 0.8°C every 5 minutes.

In Phase 2, the study design called for three metabolic demands: light demand, metabolic rate of 80 W/m^2 (M1); moderate demand, metabolic rate of 160 W/m^2 (M2); and heavy demand, with a metabolic rate of 240 W/m^2 (M3). Actual metabolic rates were calculated using oxygen consumption based on open circuit indirect calorimetry and body surface area.

The environment was set at a 50% relative humidity (rh). The starting temperature for the trials was set at 34°C, but varied based on the ensemble being worn and individual. When participants reached thermal equilibrium, T_{db} was increased 1°C every 5 minutes.

Trials

The trials were conducted in a Model 7010 climatic chamber designed by Forma Scientific. The chamber was 2.4 m wide, 3.0 m deep, and 2.2 m high (8.0 x 10.0 x 7.3 ft). The range of humidity was 10-90% and the temperature range was 4-60°C (40-140°F). Temperature and humidity were controlled according to protocol and air speed

was 0.5 m/s. The work demand consisted of walking on a motorized treadmill at a speed and grade set to elicit the desired metabolic rate (80, 160, or 240 W/m^2).

Heart rate was monitored using a Polar heart rate monitor. Core temperature was measured with a flexible YSI thermistor (401AC) inserted 10 cm beyond the anal sphincter muscle. The thermistor was calibrated prior to each trial using a hot water bath. Skin temperatures were measured with an YSI surface thermistor (409AC) taped to the skin at four points (left chest, right upper arm, right thigh, and left calf). Average skin temperature was determined using a modified Ramanathan Technique as shown in the following equation [7]:

$$T_{sk} = 0.3\ T_{chest} + 0.3\ T_{arm} + 0.2\ T_{thigh} + 0.2\ T_{calf} \tag{25}$$

Assessment of oxygen consumption was used to establish metabolic rate. Participants breathed through a two-way valve connected to flexible tubing that was connected to a collection bag (Douglas bag). Expired gases were collected every 30 minutes during the experiments for 2.5 minutes. The volume of expired air was measured using a dry gas meter. A small aliquot was removed from the Douglas bag and drawn through a drying agent (DriRite) into a Beckman Model E2 Oxygen Analyzer to determine oxygen content. Oxygen consumption (VO_2) was calculated according to Equation 25.

$$VO_2 = V_E \cdot \Delta O_2 \cdot CF \qquad (26)$$

Where, V_E was the expired air flow rate in liters per minute, ΔO_2 was the difference in the fraction of oxygen between the inspired and expired air, and CF was a correction factor to convert the volume to standard temperature and pressure dry (STPD) [35].

During trials, participants were allowed to drink water or a commercial fluid replacement beverage at will.

Core temperature, heart rate and ambient conditions (dry bulb, psychrometric wet bulb and globe temperatures) were monitored continuously and recorded every 5 minutes. Trials lasted approximately 120 minutes unless one of the following criteria was met: (1) a clear rise in T_{re} associated with a loss of thermal equilibrium, (2) T_{re} exceeded 39 °C, (3) a sustained heart rate greater than 85% of the age-predicted maximum heart rate, or (4) participant wished to stop.

The order of the ensemble-environment conditions was randomized. Any trial that had to be repeated was repeated at the end. An experimental trial data dictionary is presented with the data for each phase in the appendices. Phase 1 data are provided in Appendix B and Phase 2 data are in Appendix C.

Critical Conditions

By evaluating the point at which a clear rise in T_{re}, associated with a loss of thermal equilibrium, the critical condition ($E_{req} = E_{max}$) can be determined by using the data point preceding this rise. At the point of critical conditions $R_{e,T}$ can be calculated using Equation 12. In this equation there are two unknowns, $R_{e,T,dyn}$ and $I_{T,dyn}$. The $I_{T,Stat}$ values were calculated from measured insulation values (clo) according to ASTM F 1291, Standard Test Method for Measuring the Thermal Insulation of Clothing using a Heated Manikin, Option #1 [12].

The insulation provided by clothing (clo) was measured using an electrically-heated manikin in thermal equilibrium with the surrounding environment. The manikin is a full size male with 19 electrically separate segments. The manikin has knee, hip, shoulder, and elbow joints that can be flexible or locked in an immobile position [11].

Measurement and control of the heat supply for each section is achieved by using a digital process computer. Display and recording of the data is conducted by a second computer which is serially interfaced with the process. Temperature readings and power input values for each segment are area weighted when calculating the total insulation value [11].

The insulation value (clo) was measured according to ASTM F 1291, Standard Test Method for Measuring the Thermal Insulation of Clothing using a Heated Manikin, Option #1 [11]. The chamber had an ambient air temperature of 20°C, dew point temperature was controlled at 1°C and air velocity of 0.2 m/s, and the manikin surface temperature was set at 33.2°C.

To test each ensemble, the manikin was dressed in an ensemble with all closures secured. It was hung from a metal stand by a hook in the head. The feet touched the floor with the arms hung at the sides. Equilibrium was maintained for at least one hour prior to testing. Data were collected by computer every 30 seconds for the 30 minute test [11].

The $I_{T,dyn}$ values were calculated for each ensemble by adjusting the $I_{T,stat}$ values for wind and speed as suggested by Havenith et al [32].

Additionally, measured trial data was used to compute other variables (ΔT, ΔP and M) needed to compute $R_{e,T}$. The metabolic rate was computed based on O_2 consumption using Equations 14, 15 and 26. The equations for differences in temperatures and partial pressures are shown below.

$$\Delta T = T_{db} - T_{sk} \tag{27}$$

$$\Delta P = P_{sk} - P_a \tag{28}$$

$$P_{sk} = 0.6105 \times e^{\left(17.27 \times T_{sk} / (T_{sk} + 237.3)\right)} \tag{29}$$

$$P_{sk} = 0.6105 \times e^{\left(\left(17.27 \times T_{sk} / (T_{sk} + 237.3)\right) - 0.067 \times \left(T_{db} - T_{pwb}\right)\right)} \tag{30}$$

where ΔP is the difference in partial pressure of water vapor between the skin and ambient air.

Statistical Analysis

Statistical analysis included general descriptive statistics and linear modeling. The primary data analysis was conducted with analysis of variance (ANOVA) and verified with the Mixed Procedure. If a significant difference among ensembles was found at $\alpha = 0.05$, Tukey's Honestly Significantly Different (HSD) was calculated [36]. If the difference between any treatment mean value was greater than the HSD, then the difference was determined to be statistically different.

The data were reviewed for outliers defined as data points exceeding the mean ± two times the standard deviation. A Sharpio-Wilkes statistical test for fit was performed on the ensemble datasets to determine the best fit of the data (normal or log normal). All

of the data fit well as being normally distributed. The data (participant, ensemble, protocol, and $R_{e,T}$) were imported into SAS version 8.2.

Since the data were not balanced, the data was analyzed using a mixed linear model as well as the standard liner model (GLM) for comparison. The mixed procedure fits a variety of mixed linear models to data and enables these fitted models to make statistical inferences about the data. A mixed linear model is a generalization of the standard linear model used in the GLM procedure, the generalization being that the data are permitted to exhibit correlation and non-constant variability. The mixed linear model, therefore, provides the flexibility of modeling not only the means of the data (as in the standard linear model) but their variances and covariances as well [37].

The primary assumptions underlying the analyses performed by SAS model Proc Mixed (PM) are as follows: the data are normally distributed (Gaussian), the means of the data are linear in terms of a certain set of parameters, the variances and covariances of the data are in terms of a different set of parameters, and they exhibit a structure matching one of those available in PM [37].

The fixed-effects parameters are associated with known explanatory variables, as in the standard linear model. These variables can be either qualitative (as in the traditional analysis of variance) or quantitative (as in standard linear regression). However, the covariance parameters distinguish the mixed linear model from the standard linear model.

The need for covariance parameters arises quite frequently in applications. The most typical scenarios include: (1) the experimental units on which the data are measured can be grouped into clusters, and the data from a common cluster are correlated, and (2) repeated measurements are taken on the same experimental unit, and these repeated measurements are correlated or exhibit variability that changes.

PM provides a variety of covariance structures to handle the previous two scenarios. The most common of these structures arises from the use of random-effects parameters, which are additional unknown random variables assumed to impact the variability of the data. The variances of the random-effects parameters, commonly known as variance components, become the covariance parameters for this particular structure. Traditional mixed linear models contain both fixed- and random-effects parameters, and, in fact, it is the combination of these two types of effects that led to the name mixed model. Proc Mixed fits not only these traditional variance component models but numerous other covariance structures as well.

PM computes several different statistics suitable for generating hypothesis tests and confidence intervals. The validity of these statistics depends upon the mean and variance-covariance model selected. The independent variable was $R_{e,T}$ with three dependent variables (ensemble, protocol, and participant). For the PM model, participant was set as

the random-effect parameter, and for three-way ANOVA participant was part of the class statement.

Once significance was detected, Tukey's HSD test was used to test all pair-wise comparisons among $R_{e,T}$ means to determine which ensembles were significantly different. Interaction between two variables was also evaluated (ensemble x protocol). Significance levels were set at $\alpha = 0.05$. Three hypothesis' were tested: (1) there are no differences between mean $R_{e,T}$ values among ensembles, (2) there are no differences between mean $R_{e,T}$ values among environments and metabolic rates/demands, and (3) there are no differences between mean $R_{e,T}$ values while ΔP changes within environments and metabolic demands.

RESULTS

The primary purpose of this paper was to explore the methodology for distinguishing between garments based on the total evaporative resistance properties within different environments and work demands. The secondary purpose is to challenge the relationship of $R_{e,T}$ with respect to changes in ΔP ($P_{sk} - P_a$) and E_{max}. Experimental trials were conducted to determine the evaporative resistance for five clothing ensembles. The protocols included a fixed metabolic demand under three different relative humidity levels for Phase 1, and for three metabolic demands with a fixed relative humidity level for Phase 2. The hypothesis' tested include: (1) there are no differences between mean $R_{e,T}$ values among ensembles, (2) there are no differences between mean $R_{e,T}$ values among environments and metabolic rates/demands, and (3) there are no differences between mean $R_{e,T}$ values while ΔP changes within environments and metabolic demands.

Experimental Data

At the critical conditions measured data captured included heart rate (HR), rectal temperature (T_{re}), skin temperatures (calf, thigh, upper arm, and chest), and environmental conditions (humidity and dry, wet, and black bulb temperatures). Oxygen

(O_2) consumption was measured and recorded at 30 minute intervals (at 30, 60 and 90 minute point).

Using the measured data, other key components were computed. The metabolic rate (M) was computed using Equation 14 and the differences in temperatures and partial pressures (ΔT and ΔP) were calculated using Equations 27 – 30. The data for the critical conditions for all the trials are provided in Appendix B for Phase 1 and Appendix C for Phase 2.

Total Insulation

Results were reported as $I_{T,Stat}$ values and then converted to $I_{T,dyn}$ by adjusting for wind and movement as suggested by Havenith et al [32] as shown in Equation 20. Results for both static and dynamic values are presented in Table 3.

Table 3. Total Insulation Values for Ensembles.

Clothing Item			$I_{T,stat}$	$I_{T,dyn}$ 80 W/m^2	160 W/m^2	240 W/m^2
Ensemble A	-- (WC) --	Work Clothes	0.180	0.168	0.147	0.133
Ensemble B	-- (CC) --	Cotton Coverall	0.196	0.182	0.160	0.145
Ensemble C	-- (PB) --	Tyvek 1424	0.191	0.178	0.156	0.141
	-- (PB) --	Tyvek 1427	0.190	0.177	0.155	0.140
Ensemble D	-- (WB) --	Water Barrier	0.189	0.176	0.154	0.140
Ensemble E	-- (VB) --	Vapor Barrier	0.185	0.172	0.151	0.137

Phase 1

In Phase 1, the primary focus was to determine if the methodologies used can distinguish differences among the five selected ensembles (WC – work clothes, CC – cotton coveralls, PB – particle barrier, WB – water barrier, and VB – vapor barrier) and evaluate how the environment affects $R_{e,T}$. There were three different environments (R2 – hot/dry, R5 – moderate, and R7 – warm/humid) with a fixed moderate metabolic demand (M2) of 160 W/m^2. The average $R_{e,T}$ values and standard deviations are presented in Table 4.

Table 4. Phase 1 – Mean $R_{e,T}$ Values with Standard Deviations.

	All Data		R2		R5		R7	
Ensemble	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
A	0.013	0.0040	0.017	0.0035	0.012	0.0029	0.011	0.0029
B	0.014	0.0047	0.018	0.0046	0.012	0.0035	0.012	0.0035
C	0.015	0.0052	0.020	0.0042	0.014	0.0043	0.013	0.0047
D	0.017	0.0053	0.021	0.0039	0.016	0.0051	0.014	0.0046
E	0.027	0.0089	0.034	0.0100	0.026	0.0051	0.021	0.0065

A Sharpio-Wilkes statistical test for fit was performed on all datasets to determine the best fit of the data (normal or log normal). All of the data fit well as being normally distributed. The data were analyzed using the mixed procedure and using a three-way analysis of variance (ANOVA). The main effects included three protocols, five ensembles and 14 participants. Not all participants completed all trials and some trials were repeated which resulted in an unbalanced design. Using SAS 8.1, the Mixed and GLM models were used to determine statistical differences for $R_{e,T}$ among ensembles,

environments, and participants. Participants were treated as a blocking variable. The SAS code used and data output for Phase 1 is provided in Appendix D.

Very significant differences ($p<0.0001$) were found for ensemble, environment, and participant. Tukey's HSD test was performed to determine which pairs were significantly different among ensembles and environments. This resulted with Ensemble E being different from all other Ensembles and Ensemble D being different from Ensembles A and B. This is depicted graphically along with the mean $R_{e,T}$ values for ensembles in Figure 2. The lines below the ensembles indicate ensembles that are statistically similar.

Ensemble E was very different from the other ensembles and could have interfered with the ability to differentiate differences among the ensembles. Therefore the data were analyzed again with Ensemble E excluded. In this analysis, Ensemble D was different from all other ensembles and Ensemble A was statistically different from Ensemble C. These data are presented in Figure 3.

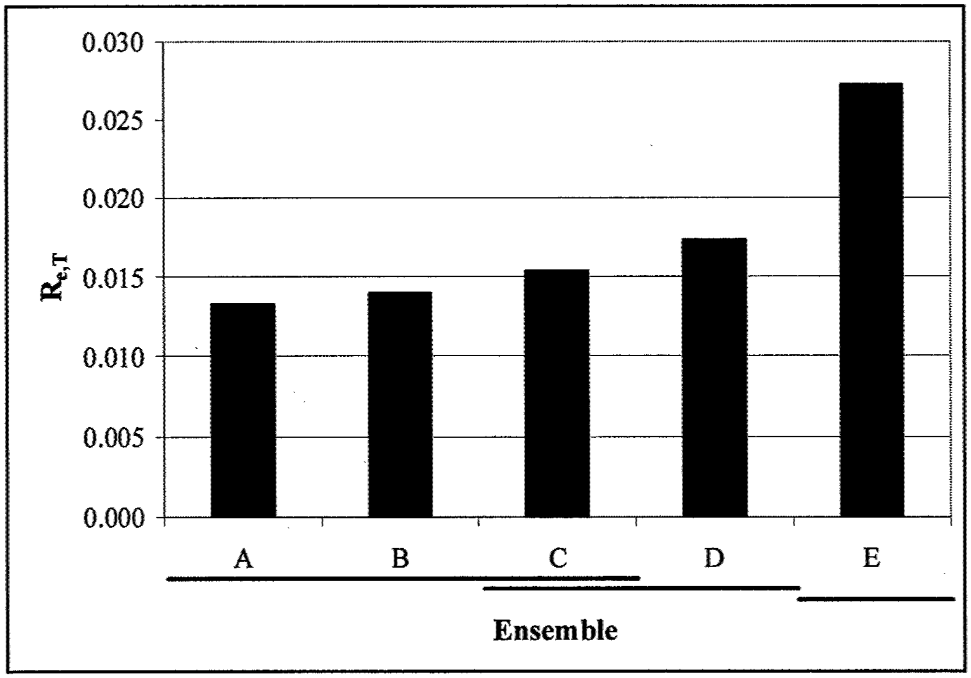


Figure 2. Phase 1 – Mean $R_{e,T}$ by Ensemble.

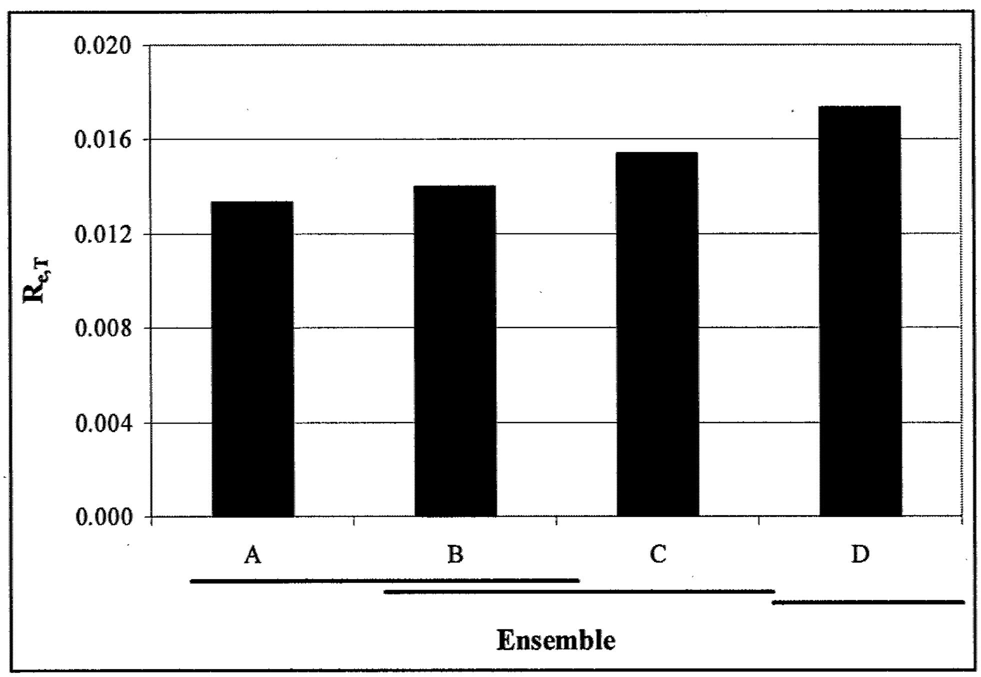


Figure 3. Phase 1 – Mean $R_{e,T}$ by Ensemble w/o Ensemble E.

Interaction between ensemble and environment was tested and found to be significant ($p=0.0187$) with Ensemble E in the mix and not significant ($p=0.8820$) when analyzed without Ensemble E. The interaction between environment and ensemble can be seen graphically in Figure 4.

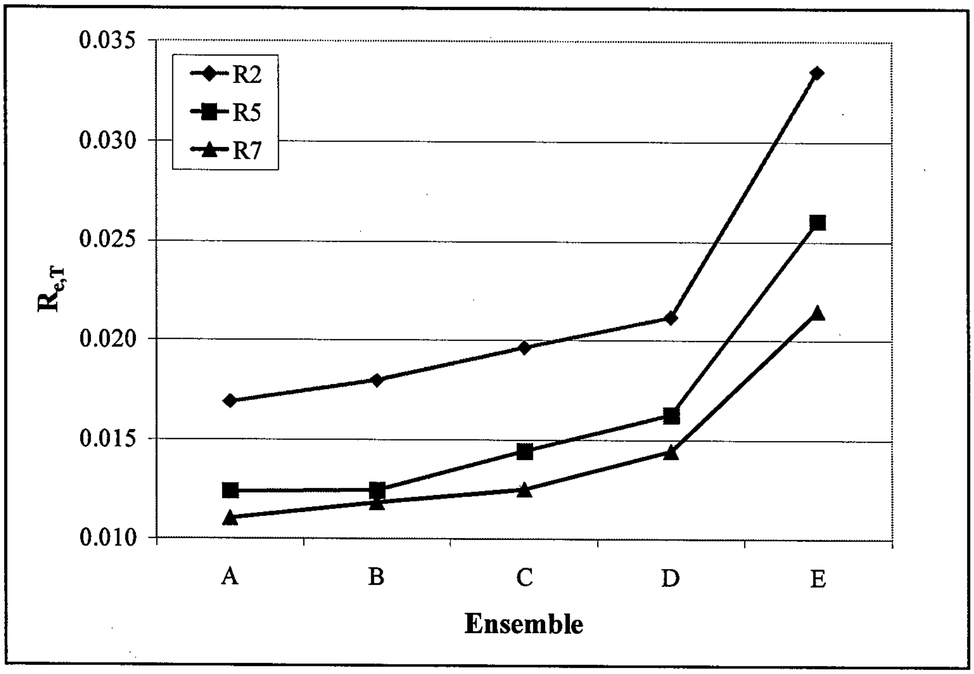


Figure 4. Phase 1—Mean $R_{e,T}$ Values by Ensemble and Environment.

The statistical software JMP-IN 5.1 was used to analyze the mean $R_{e,T}$ values for each environment within an ensemble. This resulted with all ensembles being very significantly different within each environment ($p< 0.001$).

Analysis of $R_{e,T}$ by environment resulted with the environment being significantly different. Tukey's HSD detected all pairs to be very significantly different ($p<0.001$). Figure 5 presents the mean $R_{e,T}$ values by environment and indicates that all environments are statistically different from the others.

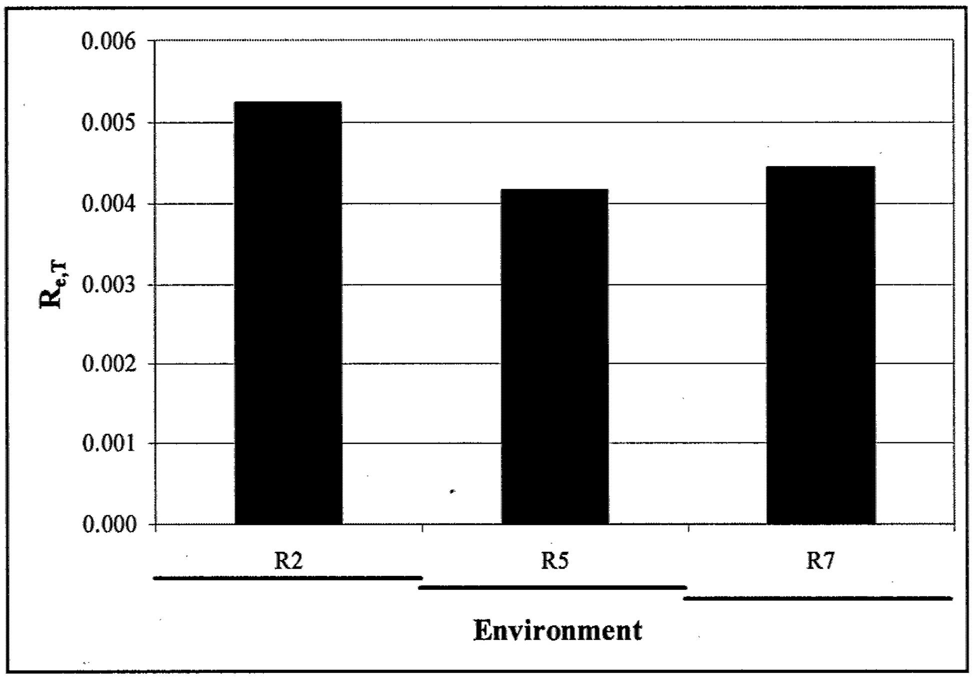


Figure 5. Phase 1—Mean $R_{e,T}$ Values by Environment.

The statistical software JMP-IN 5.1 was used to analyze the mean $R_{e,T}$ values for each environment within an ensemble. This resulted the $R_{e,T}$ values being significantly different between environments for all Ensembles ($p<0.001$).

Phase 2

In Phase 2, the primary focus was to verify the methodologies used can distinguish differences among the five selected ensembles (WC – work clothes, CC – cotton coveralls, PB – particle barrier, WB – water barrier, and VB – vapor barrier) and evaluate how the metabolic rate affects $R_{e,T}$. There were three different metabolic rates (M1 – light work, M2 – moderate work, and M3 – heavy work) with a fixed moderate environment (R5) at 50% rh. The average $R_{e,T}$ values and standard deviations are presented in Table 5.

Table 5. Phase 2 – Mean $R_{e,T}$ Values with Standard Deviations.

	All Data		M1		M2		M3	
Ensemble	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
A	0.011	0.002	0.011	0.002	0.013	0.003	0.011	0.001
B	0.012	0.003	0.014	0.003	0.012	0.002	0.011	0.003
C	0.013	0.003	0.015	0.004	0.012	0.002	0.011	0.001
D	0.015	0.004	0.018	0.005	0.015	0.002	0.012	0.002
E	0.024	0.006	0.028	0.005	0.024	0.004	0.019	0.003

The data were reviewed for outliers and 20 out of 226 data points exceeded the mean ± two times the standard deviation. A Sharpio-Wilkes statistical test for fit was performed on all datasets to determine the best fit of the data (normal or log normal). All of the data fit well as being normally distributed. The data were analyzed using the mixed procedure and using a three-way analysis of variance (ANOVA). The main

effects included three protocols, five ensembles and 15 participants. Not all participants completed all trials and some trials were repeated which resulted in an unbalanced design. Using SAS 8.1, the Mixed and GLM models were used to determine statistical differences for $R_{e,T}$ among ensembles, metabolic rates, and participants. Participants were treated as a blocking variable. The SAS code used and data output for Phase 2 is provided in Appendix E.

Very significant differences ($p<0.0001$) were found for ensemble, metabolic rate, and participant ($p<0.0001$). Tukey's HSD test was performed to determine which pairs were significantly different among ensembles and environments. This resulted with Ensembles D and E being different from all other ensembles. There was no statistical difference detected when analyzing the data with and without outliers, therefore the complete dataset was used for all data references. Figure 6 depicts the mean $R_{e,T}$ values by ensembles graphically. The lines below the ensembles indicate ensembles that are statistically similar.

Analysis of $R_{e,T}$ by metabolic rate resulted with the environment being significantly different. Tukey's HSD detected all pairs to be very significantly different ($p<0.0002$). Figure 7 presents the mean $R_{e,T}$ values by environment and indicates that all environments are statistically different from the others.

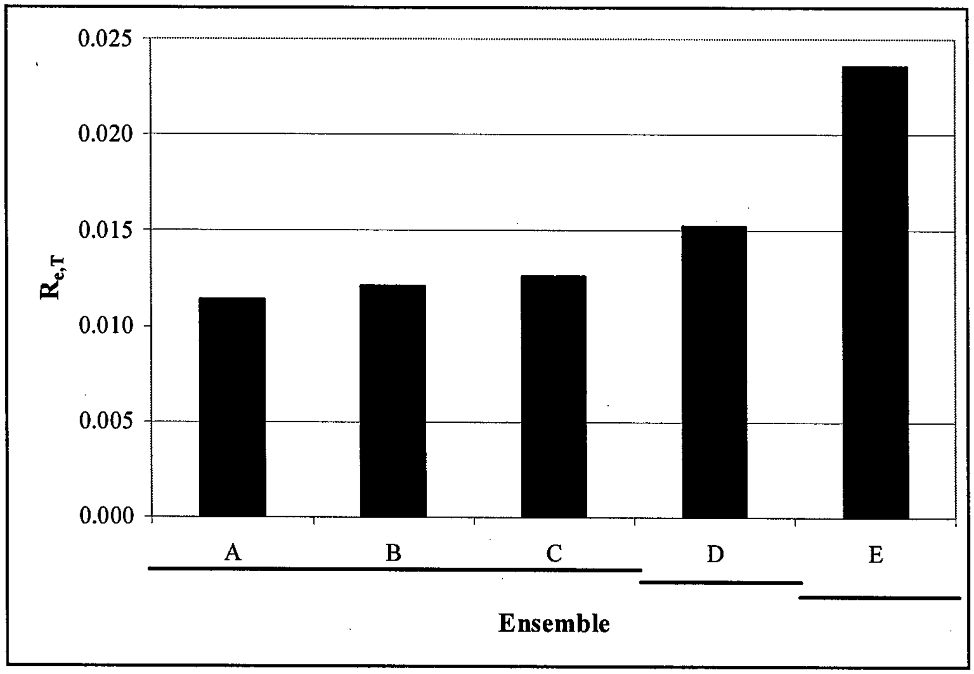


Figure 6. Phase 2 – Mean $R_{e,T}$ by Ensemble.

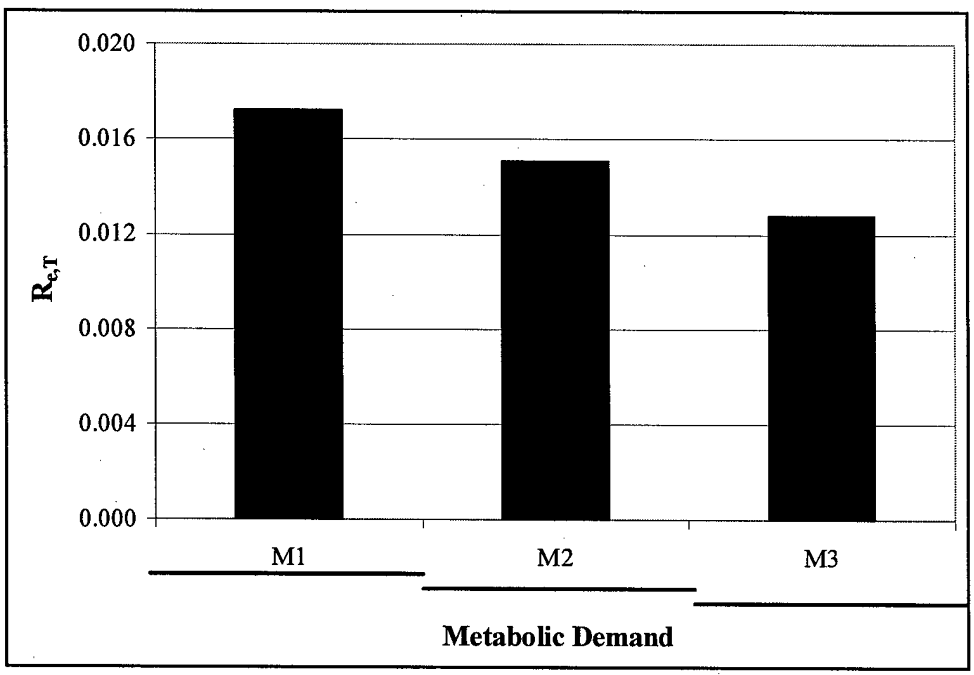


Figure 7. Phase 2 – Mean $R_{e,T}$ by Metabolic Rate.

All trials were designed for the participants to elicit a desired metabolic rate based on varying the speed and grade of the treadmill for each individual. During Phase 2 there were three desired metabolic rates 80 W/m^2, 160 W/m^2, and 240 W/m^2. The average metabolic rates by protocol are provided in Table 6 and shown graphically in Figure 8.

Table 6. Phase 2 – Average Metabolic Rates.

Ensemble	M1	M2	M3	Avg
A	121	175	250	183
B	118	177	241	178
C	108	178	251	177
D	111	177	259	182
E	114	176	249	181
Average	114	176	250	

Interaction between ensemble and metabolic rate was tested and found to be very significant ($p<0.0001$). The interaction between metabolic rate and ensemble can be seen graphically in Figure 9.

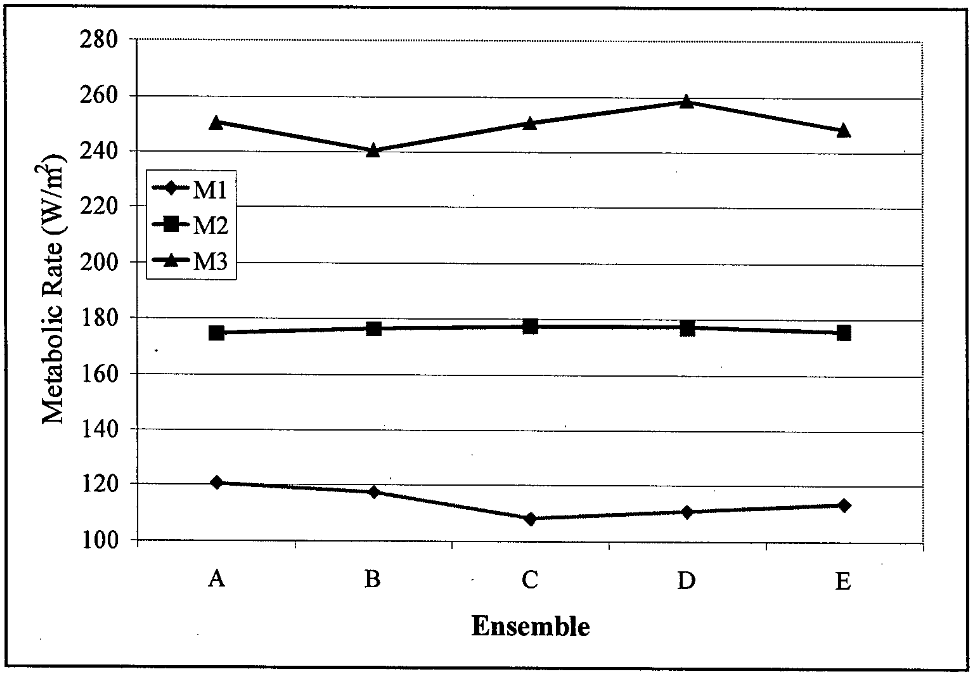


Figure 8. Phase 2 – Average Metabolic Rates by Ensemble.

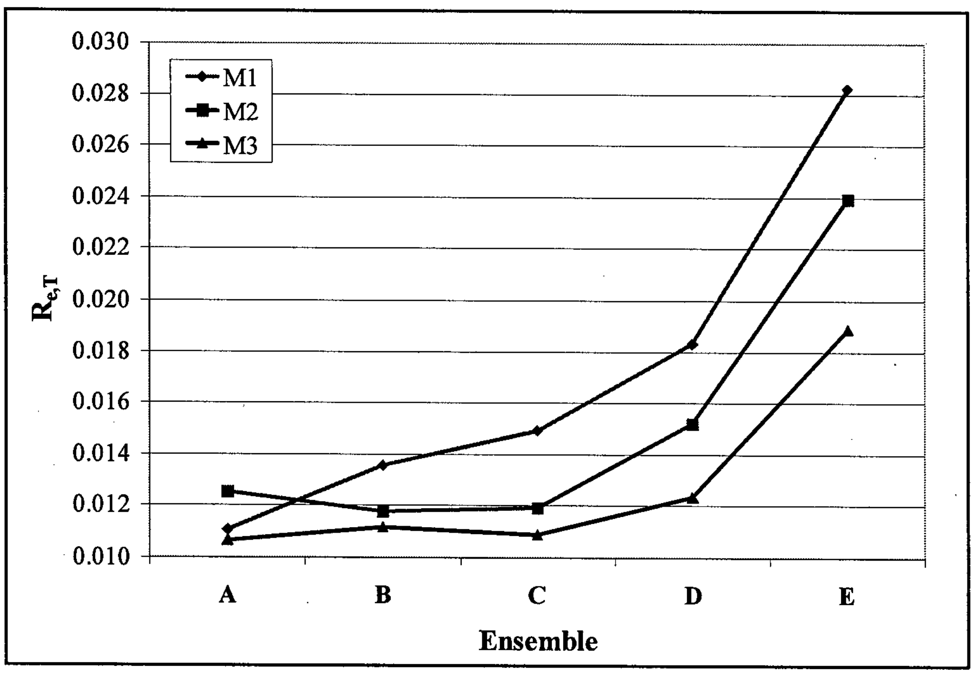


Figure 9. Phase 2 – Mean $R_{e,T}$ by Metabolic Rate and Ensemble.

Looking for where the interaction might occur, the statistical software JMP-IN 5.1 was used to analyze the mean $R_{e,T}$ values for each metabolic rate within an ensemble. This resulted the $R_{e,T}$ values not being significantly different between metabolic rates within Ensemble A ($p=0.0717$) and B ($p=0.0610$), and very significantly different for Ensembles C, D, and E ($p<0.001$). The complete JMP-IN analysis of Phase 1 and 2 (protocols) is provided in Appendix F.

DISCUSSION

The focus of this study was to conduct experimental trials to explore two research areas. First, trials were conducted to distinguish among garments based on the total evaporative resistance properties between different environments and work demands. Experimental trials were conducted in each phase to determine the evaporative resistance for five selected clothing ensembles. The protocols included a fixed metabolic demand under three different relative humidity levels for Phase 1, and for three metabolic demands with a fixed relative humidity level for Phase 2. Second, the data from the experimental trials were used to discern weather or not the generally accepted theory that $R_{e,T}$ remains constant.

Internal Validity

Phase 1 and 2 both had one protocol that had the same design -- a moderate work rate (M2 – 160 W/m^2) and a moderate environment (R5 – 50% rh). Ensemble C (PB) was changed between Phase 1 and 2, but the other ensembles remained the same. Some of the same participants from Phase 1 were used again in Phase 2, but most were different. Comparing the moderate work rate and moderate environment (M2R5) data from both phases provided internal validity to the methodology. The mean $R_{e,T}$ values for

ensembles for Phase 1 and 2 were plotted and presented in Figure 10. The average metabolic rates for Phase 1 and 2 are provided in Figure 11.

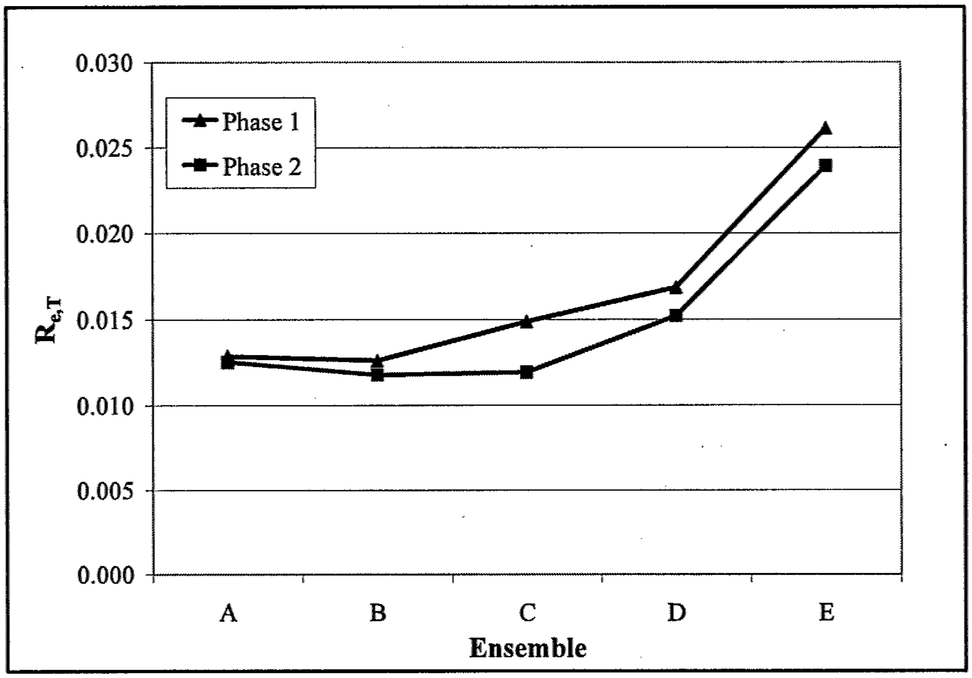


Figure 10. Comparison of M2R5 Mean $R_{e,T}$.

In Figure 10 the grouping of data points for each ensemble appears to be tightly correlated with the exception of Ensemble C. As discussed previously, Ensemble C was changed from a Tyvek 1424 for Phase 1 to Tyvek 1427 for Phase 2. Statistical analysis using JMP-IN 5.1 was used to analyze the M2R5 data to compare mean $R_{e,T}$ values within ensembles. This analysis resulted with only Ensemble C being significantly different ($p=0.0349$). The statistical results (p values) and mean $R_{e,T}$ values are provided in Table 8. The JMP-IN analysis is provided in Appendix G.

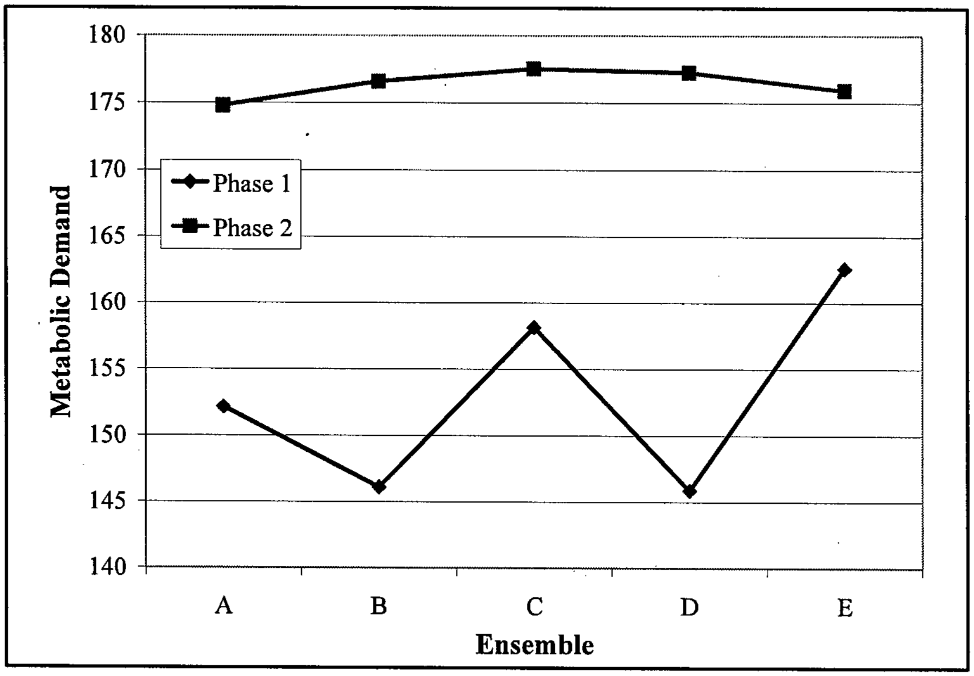


Figure 11. Comparison of M2R5 Mean Metabolic Demands.

Table 7. Statistical Analysis of M2R5 Dataset.

		Mean $R_{e,T}$	
Ensemble	p Value	Phase 1	Phase 2
A	0.7692	0.013	0.013
B	0.4741	0.013	0.012
C	0.0349	0.015	0.012
D	0.2577	0.017	0.015
E	0.1653	0.026	0.024

At first glance, the metabolic rates seen in Figure 11 appear to be significantly different. However, the scale is compressed making the small differences (< 10%) seem larger. The differences in Phase 1 and 2 were not enough to change the conformation of internal validity.

Comparison to Other Studies

Total Insulation

In order to determine the evaporative resistance, an understanding of the ensemble properties must be understood. The clothing properties were derived from manikin experiments conducted at the Institute for Environmental Research, Kansas State University by Dr. Elizabeth McCullough. Using her manikin, and following ASTM F 1291, she was able to determine the total clothing insulation ($I_{T,stat}$), intrinsic clothing insulation (I_{cl}) and the clothing area factor (f_{cl}) for the six ensembles used in the experimental trials. As reported by Havenith et al. [25] heated manikin results for standing/no wind appears to be on average 0.023 °C m^2/W higher than human participants. While some studies support this claim, other studies find the manikin data as being lower than human participants. After adjusting for wind and movement the $I_{T,dyn}$ values were compared to other studies that had similar ensembles. The studies included Barker et al. [23], Kenney et al. [21], and Bernard and Matheen [9]. After adjusting the I_T values, the values used in this study are clearly higher than other studies for similar ensembles. The reported I_T values are shown in Table 9.

Table 8. I_T Values from Different Studies.

I_T (m^2 K/W)				
Ensemble	Current	Barker	Kenney	Bernard
A	0.147	0.084	0.050	
B	0.160	0.107	0.056	0.107
C	0.156	0.086	0.059	
D	0.154	0.086	0.050	
E	0.151	0.086	0.035	

The Barker et al. and Bernard and Matheen studies reported I_T values that were 33 – 45% lower, and the Kenney et al. study reported values that were 62 - 77% lower. A primary difference in all of these studies is the adjustment for wettedness. Although there isn't a set standard for adjusting for clothing wettedness thus far, many researchers use a 50% default adjustment. The Barker at al. and Bernard and Matheen studies both used a 45% adjustment for wettedness. Had the current values been adjusted for wettedness, the I_T values would match the Barker et al. study very well. On the other hand, Kenney et al. used a simultaneous derivation method to compute I_T. Using his methodology to compute I_T with the Phase 1 data resulted in too much variation in I_T to make it useful.

On the face of it, having a good estimate of the I_T is important because it is used to compute $R_{e,T}$. However, Barker et al. demonstrated that relatively large changes in I_T result in minor changes in $R_{e,T}$. Therefore the manikin data adjusted for wind and movement is sufficient for determining the I_T of the ensembles used.

Total Evaporative Resistance

In 1993 Kenney at al. [19], building from previous research, setup the framework for conducting human experiments in a climate controlled heated chamber. The methodology they established is still in use.

Using the principle of the prescriptive zone as established by Lind [15], the determination of the inflection point is established by selecting the point preceding a rise in T_{re}. At the inflection point, critical conditions exist where $S = 0$ and $E_{max} = E_{req}$. From these conditions the basic heat balance equation can be manipulated by substituting terms for E_{max} and E_{req} and solving for $R_{e,T}$.

Similarly to the I_T values, mean $R_{e,T}$ values were compared to the same studies – Barker et al. [23], Kenney et al. [21], and Bernard and Matheen [9]. Although there were large differences (33 – 45% lower I_T values reported by Barker et al. and 62 – 77% lower values reported by Kenney et al.), the $R_{e,T}$ values had less differences as shown in Table 10.

Table 9. $R_{e,T}$ Values from Different Studies.

$R_{e,T}$ (kPa m^2/W)				
Ensemble	Current	Barker	Kenney	Bernard
A	0.0133	0.0131	0.0092	
B	0.0140	0.0159	0.0096	0.0155
C	0.0154	0.0163	0.0112	
D	0.0174	0.0176	0.0123	
E	0.0273	0.0136	0.0344	

Barker et al. reported three $R_{e,T}$ values that were within 6%, one at 14% and one at 50% (vapor barrier suit). Kenney et al.'s values ranged from 26 – 32% difference, and Bernard and Matheen's reported value was 11% higher. Barker's I_T values were close to the ensembles used in this study with the exception of not adjusting these values by 45% for account for wettedness. However, even with the 45% difference in I_T, there is minor differences in $R_{e,T}$. Barker et al. had previously reported this relationship, and this study supports it. Based on the Barker et al. and Bernard and Matheen studies, the $R_{e,T}$ values calculated in this study appear in line with other research.

Phase 1

The methodology used was able to distinguish effectively between the selected ensembles as illustrated in Figures 2 and 3 showing significant differences among Ensembles D and E. Since Ensemble E is a vapor barrier suit, it is expected to be different from ensembles that do not prevent vapor transmission such as cotton and Tyvek coveralls. Similarly, Ensemble D is a liquid barrier suit, so it is also expected to

be different from particle barrier and cotton clothing (Ensembles A, B and C) with respect to evaporative resistance.

In Figure 4 there is a clear difference between environments. The differences between the mean $R_{e,T}$ values remains the same within Ensembles A – D, but increases for Ensemble E. The increase difference accounts for the interaction between the environment and ensemble and is verified by not seeing an interaction when the data is analyzed without Ensemble E.

The fact that there is a difference between environments is by itself an important finding. The relationship between $R_{e,T}$ and ΔP with respect to E_{max} (Equation 10) has generally been accepted that $R_{e,T}$ remains constant as ΔP and E_{max} change. This relationship is alluded to in ISO 7933 and discussed by Parsons (2003) [7].

Again, Figure 4 clearly shows that $R_{e,T}$ is not the same as the environment changes. Using the data from Phase 1 and Phase 2, ΔP was plotted against $R_{e,T}$ to test this theory. The data were plotted for each ensemble across all protocols and a regression line was calculated. All of the graphs are presented in Appendix H, and the graph for Phase 1 Ensemble A is shown in Figure 12. It is obvious that $R_{e,T}$ does not remain constant as ΔP changes, and the rate of change (slope) appears constant within Phase 1 for the different ensembles suggesting that environment is a factor. However, the Phase 2 graphs do not show any consistent effect for activity. The Phase 2 data is confounded by the metabolic

rate and therefore there isn't an expected effect. Regression analysis performed on the data resulted with Phase 2 ensembles having an R-square value of 0.002 – 0.115, while the Phase 1 ensembles ranged from 0.388 – 0.617.

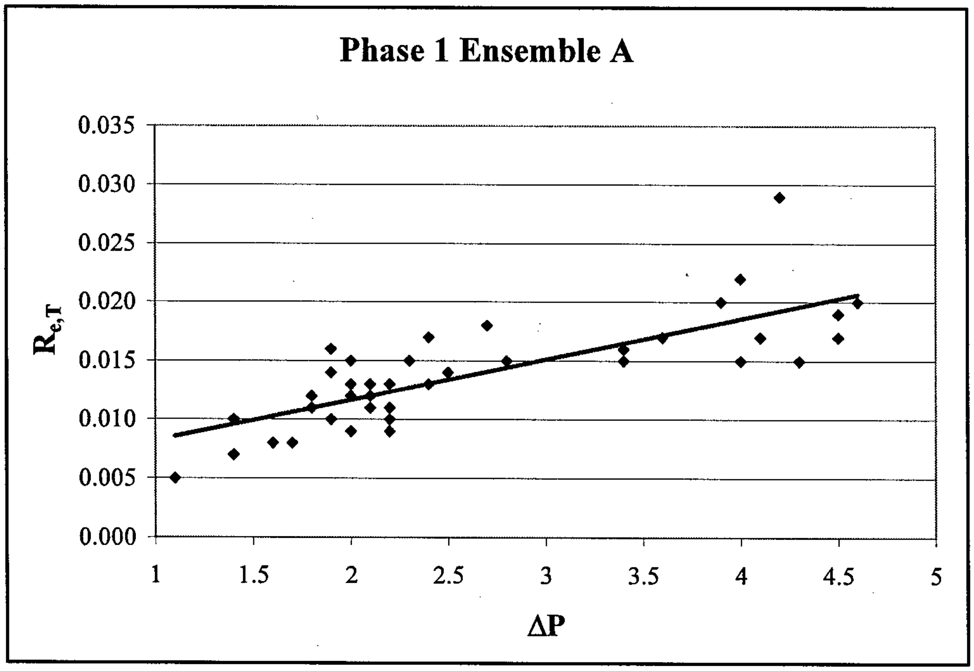


Figure 12. Effect of Environment: $R_{e,T}$ vs. ΔP – Ensemble A.

Table 10 presents the slopes and intercepts of the regression analysis. By reviewing the slope values, environment (Phase 1) appears to have consistent and significant slope values across the ensembles. However, the values for Phase 2 suggest the slopes are neither consistent nor significant. Although Ensemble A in Phase 2 presents a good positive slope, all of the other ensembles do not.

Table 10. Regression Analysis – ΔP by $R_{e,T}$

	Phase 1			Phase 2		
Ensemble	R2	Slope	Intercept	R2	Slope	Intercept
A	0.617	0.0001	0.0004	0.115	0.0244	0.0001
B	0.453	0.0001	0.0025	0.018	0.3951	0.0007
C	0.477	0.0001	0.0037	0.001	0.8478	0.0001
D	0.388	0.0001	0.0002	0.001	0.8420	0.0009
E	0.534	0.0001	0.7474	0.005	0.6430	0.0006

Phase 2

Similar to Phase 1, the methodology used was able to distinguish effectively between the selected ensembles as illustrated in Figure 6, showing very significant differences among Ensembles D and E as compared to Ensembles A, B, and C. Figure 7 indicates $R_{e,T}$ decreases as the metabolic rate increases. The interaction between ensemble and metabolic rate is clearly seen by observing the differences between metabolic rates within each ensemble increase corresponding to the reduction to $R_{e,T}$.

There is not much difference in the mean $R_{e,T}$ values between the metabolic rates within Ensemble A indicating good evaporative cooling (high permeability). However, progressing through the ensembles, the differences between protocols increases indicating the metabolic rate (activity) plays an increasing role in lowering the mean $R_{e,T}$. Again, this relationship was verified by using JMP-IN to test the differences between the protocols for each ensemble. Ensemble A and B were not significantly different whereas the others (Ensembles C, D, and E) all resulted as being very significantly different.

As discussed previously, increasing the metabolic rate results with decreasing the mean $R_{e,T}$ values. This effect is presented differently in Figure 13 where the difference among ensembles is distinct for M1, but changes as the metabolic demand increases. For M1, there appears to be a step effect between the ensembles. In M2 and more so in M3, this step effect disappears as the ensembles appear to reach the lower limit of $R_{e,T}$.

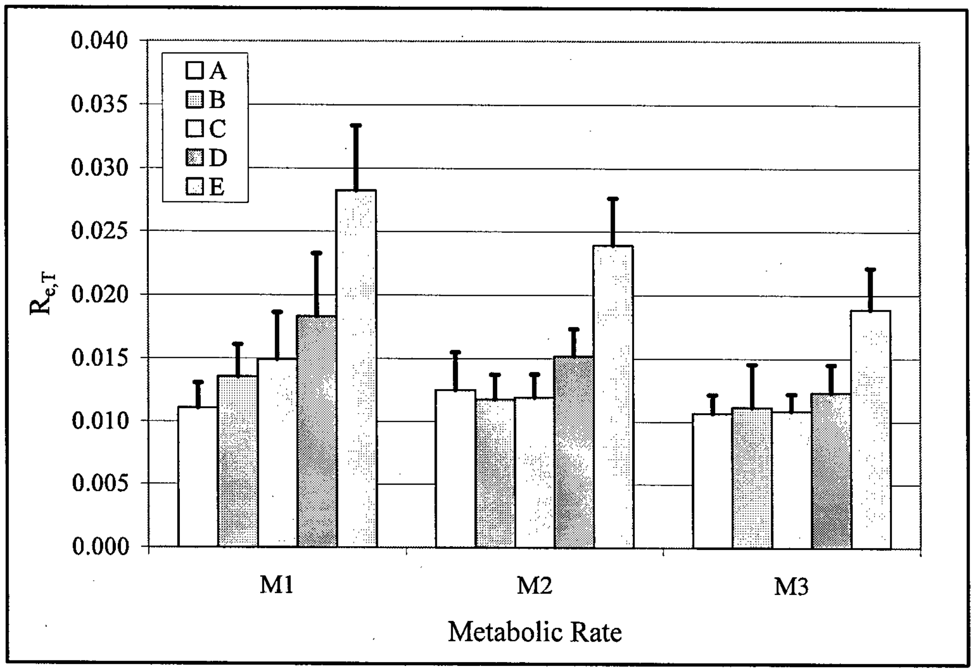


Figure 13. Effect of Metabolic Rate on $R_{e,T}$.

Havenith et al. [30] and Parsons et al. [31] explain the relative decrease in $R_{e,T}$ due to the increased air movement through the clothing. They use the term pumping action to explain that as an individual moves, air is pumped into and out of their clothing. As the air moves through the clothing, the effective I_T and $R_{e,T}$ decreases due to increased convective and evaporative cooling.

CONCLUSIONS

The primary purpose of this research was to explore the differences among garments based on the total evaporative resistance properties among different environments and work demands. The secondary purpose was to challenge the relationship of $R_{e,T}$ with respect to changes in ΔP and E_{max}. Experimental trials were conducted to determine the evaporative resistance for five clothing ensembles per phase. The protocols included a fixed metabolic demand under three different environments (levels of relative humidity) for Phase 1, and a fixed relative humidity level with three metabolic demands with for Phase 2. The fundamental step in these studies was being able to distinguish the point just before the transition of compensable heat stress to uncompensable heat stress ($E_{req} = E_{max}$).

Statistical analysis of the data showed that the methodology used was able to distinguish well among the selected ensembles. Data from Phase 1 found that Ensemble E was different from all others and Ensemble D was different from A and B. More importantly, the data revealed a relationship with the environment. The mean $R_{e,T}$ values for each ensemble decreases as the humidity increased. The changes to $R_{e,T}$ due to environment were explored further.

The default assumption has been that $R_{e,T}$ remains constant as ΔP changes. This relationship between $R_{e,T}$ and ΔP was challenged and found that $R_{e,T}$ does not stay constant as generally accepted. Environment (relative humidity) effects $R_{e,T}$ as well as ΔP. This relationship needs to be studied further before it is fully understood.

The Phase 2 analysis resulted with Ensembles D and E being different from all other ensembles. As expected, with increased activity mean $R_{e,T}$ values decreased. Ensembles D and E had the biggest decreases in $R_{e,T}$, while Ensembles A, B, and C appeared to reach a lower limit associated with the ensemble permeability properties. The decrease in $R_{e,T}$ from metabolic demand was related to the pumping action of air through the ensemble from movement.

The null hypothesis' were rejected for all three hypothesis' tested. The data shows (1) there are differences between $R_{e,T}$ values within ensembles, (2) there are differences between $R_{e,T}$ values within ensembles and between the different metabolic rates/demands, and (3) $R_{e,T}$ does not remain constant while ΔP changes.

REFERENCES

1. Belding, H.S. and T.F. Hatch, *Index for evaluating heat stress in terms of resulting physiological strain.* Journal of the American Society of Heating and Ventilation Engineers, 1955(Heating, Piping and Air Conditioning Section 27): p. 129-135.

2. NIOSH, *Occupational Exposure to Hot Environments*. 1986, U.S. Department of Health and Human Services: Washington DC.

3. Bernard, T.E., F.N. Dukes-Dobos, and J.D. Ramsey, *Evaluation and control of hot working environments: Part II - The scientific basis (knowledge base) for the guide.* International Journal of Industrial Ergonomics, 1994. **14**: p. 129-138.

4. Havenith, G., *Heat balance when wearing protective clothing.* Annals of Occupational Hygiene, 1999. **43**(5): p. 289-96.

5. Holmer, I., et al., *Clothing convective heat exchange--proposal for improved prediction in standards and models.* Annals of Occupational Hygiene, 1999. **43**(5): p. 329-37.

6. Goldman, R.F., *Standards for human exposure to heat*, in *Environmental Ergonomics: Sustaining Human Performance in Harsh Environments*, I.B. Mekjavic, E.B. Banister, and J.B. Morrison, Editors. 1988, Taylor & Francis: Philadelphia. p. 99-136.

7. Parsons, K., *Human thermal Environments: The effects of hot, moderate and cold environments oh human health, comfort and performance*. 2 ed. 2003, New York: Taylor and Francis.

8. ISO9920, *Ergonomics of the thermal environment: Estimation of the thermal insulation and evaporative resistance of a clothing ensemble*. 1995, International Organization for Standardization: Geneva.

9. Bernard, T.E. and F. Matheen, *Evaporative resistance and sustainable work under heat stress conditions for two cloth anticontamination ensembles.* International Journal of Industrial Ergonomics, 1999. **23**: p. 556-564.

10. ASTM, *F1868-02 Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate*. 2003, Conshohocken, PA: American Society for Testing and Materials.

11. McCullough, E.A., *Thermal Insulation Values for Clothing Ensembles*. 2003, Institute for Environmental Research, Kansas State University: Manhattan.

12. ASTM, *Annual Book of ASTM Standards -- Part 11.03*. 2002, Conshohocken, PA: American Society for Testing and Materials.

13. Nilsson, H.O., *Comfort Climate Evaluation with Thermal Manikin Methods and Computer Simulation Models*, ed. D.o.C.a.A. Engineering and S. Royal Institute of Technology. 2004, Stockholm: National Institute for Working Life.

14. Fan, J. and X. Qian, *New functions and applications of Walter, the sweating fabric manikin.* European Journal of Applied Physiology, 2004. **12**: p. 12.

15. Lind, A.R., *A physiological criterion for setting thermal environmental limits for everyday work.* Journal of Applied Physiology, 1963. **18**: p. 51-6.

16. Belding, H.S. and E. Kamon, *Evaporative coefficients for the prediction of safe limits in prolonged exposures to work under hot conditions.* Federal Proceedings, 1973. **32**(5): p. 1598-1601.

17. Kamon, E. and B. Avellini, *Physiologic limits to work in the heat and evaporative coefficient for women.* Journal of Applied Physiology, 1976. **41**(1): p. 71-6.

18. Holmer, I. and S. Elnas, *Physiological evaluation of the resistance to evaporative heat transfer by clothing.* Ergonomics, 1981. **24**(1): p. 63-74.

19. Kenney, W.L., D.E. Hyde, and T.E. Bernard, *Physiological Evaluation of Liquid-Barrier, Vapor-Permeable Protective Clothing Ensembles for Work in Hot Environments.* American Industrial Hygiene Association, 1993. **54**(7): p. 397-402.

20. Chengalur, S.N., S.H. Rodgers, and T.E. Bernard, *Kodak's Ergonomic Design for People at Work.* 2nd ed. 2004: John Wiley & Sons, Inc.

21. Kenney, W.L., et al., *Simultaneous derivation of clothing-specific heat exchange coefficients.* Medical Science of Sports Exercise, 1993. **25**(2): p. 283-9.

22. Dubois, A. and E.F. Dubois, *The Measurement of the Surface Area of Man.* Archives of Internal Medicine, 1950. **15**: p. 868-881.

23. Barker, D.W., S. Kini, and T.E. Bernard, *Thermal characteristics of clothing ensembles for use in heat stress analysis.* American Industrial Hygiene Association Journal, 1999. **60**(1): p. 32-7.

24. McCullough, E.A., B.W. Jones, and T. Tamura, *A Data Base for Determining the Evaporative Resistance of Clothing.* ASHRAE Transactions, 1989. **95**(2): p. 316-328.

25. Havenith, G., R. Heus, and W.A. Lotens, *Resultant clothing insulation: a function of body movement, posture, wind, clothing fit and ensemble thickness.* Ergonomics, 1990. **33**(1): p. 67-84.

26. Nishi, Y., R.R. Gonzales, and A.P. Gagge, *Direct measurements of clothing heat transfer properties during sensible and insensible heat exchange with thermal environment.* ASHRAE Transactions, 1975. **81**: p. 183-199.

27. Vogt, J.J., et al., *Pumping effects on thermal insulation of clothing worn by human subjects.* Ergonomics, 1983. **26**(10): p. 963-74.

28. Nielsen, R., B.W. Olesen, and P.O. Fanger, *Effect of physical activity and air velocity on the thermal insulation of clothing.* Ergonomics, 1985. **28**(12): p. 1617-31.

29. Olesen, B.W., et al., *Effect of body posture and activity on the thermal insulation of clothing: measurements by a moveable thermal manikin.* ASHRAE Transactions, 1982. **88**: p. 791-805.

30. Havenith, G., R. Heus, and W.A. Lotens, *Clothing ventilation, vapour resistance and permeability index: changes due to posture, movement and wind.* Ergonomics, 1990. **33**(8): p. 989-1005.

31. Parsons, K.C., et al., *The effects of wind and human movement on the heat and vapour transfer properties of clothing.* Annals of Occupational Hygiene, 1999. **43**(5): p. 347-52.

32. Havenith, G., et al., *Clothing evaporative heat resistance--proposal for improved representation in standards and models.* Annals of Occupational Hygiene, 1999. **43**(5): p. 339-46.

33. Craig, F.N., *Evaporative cooling of men in wet clothing.* Journal of Applied Physiology, 1972. **33**(3): p. 331-6.

34. Bernard, T.E. *Differences in Total Evaporative Resistance Due to Environment and Activity as Observed for Three Clothing Ensembles.* in *International Conference on Environmental Ergonomics*. 1998. San Diego, CA: International Conference on Environmental Ergonomics.

35. Consolazio, C.R., R.E. Johnson and L.J. Pecora. *Physiological Measurements of Metabolic Functions in Man.* New York: McGraw-Hill (1963).

36. Kuzma, J.W. and S.E. Bohnenblust, *Basic Statistics for the Health Sciences*. 4 ed. 2001, Mountain View, California: Mayfield Publishing Company. 364.

37. Littell, R.C., et al., *SAS System for Mixed Models*. 1996, Cary, NC: SAS Institute Inc.

APPENDIX A

PARTICIPANT DATA

Table A1. Characteristics of Participants in Experimental Trials.

Participant	Sex	Age (years)	Height (cm)	Weight (kg)	Surface Area (m^2)
Y1S1	M	26	180	95	2.14
Y1S2	F	26	163	52	1.55
Y1S3	M	24	183	86	2.08
Y1S4	M	25	183	77	1.99
Y1S5	F	23	152	63	1.59
Y1S6	F	27	170	91	2.02
Y1S7	M	35	189	101	2.28
Y1S8	F	39	155	46	1.42
Y1S9	M	20	183	130	2.48
Y1S10	M	30	191	110	0.00
Y1S11	M	32	173	71	1.84
Y1S12	M	43	178	112	2.28
Y1S13	M	28	185	95	2.19
Y1S14	F	44	165	65	1.72
Y2S1	F	27	163	52	1.55
Y2S2	M	28	185	95	2.19
Y2S3	F	27	170	91	2.02
Y2S4	M	26	180	95	2.15
Y2S5	M	27	175	98	2.13
Y2S6	M	20	180	83	2.03
Y2S7	M	20	183	72	1.93
Y2S8	M	24	163	64	1.68
Y2S9	M	43	149	75	1.69
Y2S10	M	49	175	86	2.02
Y2S11	F	18	170	56.8	1.66
Y2S12	F	20	157	56.8	1.57
Y2S13	M	21	185	81.8	2.06
Y2S14	M	22	175	66	1.80
Y2S15	M	28	185	86	2.11
Average ± Std Dev		28.3 ± 8.1	173.9 ± 11.5	81.1 ± 20.1	1.87 ± 0.45

APPENDIX B

EXPERIMENTAL DATA – PHASE 1

Appendix B

Experimental Data – Phase 1: Data Dictionary

Title	Description
Code	Participant Code
Gender	Gender of participant
Proto	Protocol Design: Environment (R2 (20% rh), R5 (50% rh), R7 (70% rh)) or Metabolic Demand (M1 (80 W/m^2), M2 (160 W/m^2), M3 (240 W/m^2))
Ens	Ensemble: (A (work clothes), B (cotton coveralls), C (particle barrier), D (liquid barrier), E (vapor barrier))
Tdb	Ambient air temperature (dry bulb) in degrees Celsius
Tpwb	Wet bulb air temperature in degrees Celsius
Tg	Black bulb air temperature in degrees Celsius
S(m/s)	Speed in meters per second
G(%)	Grade of treadmill in percentage
HR	Heart rate
Tre	Body core temperature (rectal)
Tch	Skin temperature at the chest
Tarm	Skin temperature at the upper arm
Tth	Skin temperature at the thigh
Tcalf	Skin temperature at the calf
Met	Calculated metabolic work based on O2 consumption in Watts
BSA	Body surface area in square meters
MSA	Met divided by the BSA (W/m^2)
Tsk	Average Skin temperature
Psk	Partial pressure of the water vapor at the skin
Pv	Partial pressure of the water vapor in the air
Psk-Pv	ΔP: Difference between Psk and Pv
Tair-Tsk	ΔT: Difference between Tdb and Tsk
ReT	Total evaporative resistance

Appendix B (Continued)

Experimental Data – Phase 1

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Tsk	Psk	Pv	BSA	Met	MSA	Psk-Pair	Tair-Tsk	ReT
S0	M	R2	A	47.7	27.4	47.7	1.31	0	102	37.7	34.4	35.0	36.0	36.1	35.2	5.7	2.3	2.14	351	164	3.4	12.5	0.015
S0	M	R5	A	42.3	31.3	42.3	1.31	0	103	38.0	36.6	36.1	36.0	36.9	36.4	6.1	3.8	2.14	365	171	2.2	5.9	0.011
S0	M	R7	A	32.5	28.4	32.5	1.30	0	89	37.7	35.1	34.1	34.6	34.6	34.6	5.5	3.6	2.14	311	145	1.9	-2.1	0.014
S0	M	R2	B	45.6	28.1	45.6	1.33	0	94	37.6	36.1	35.0	35.2	37.2	35.8	5.9	2.6	2.14	347	162	3.2	9.8	0.015
S0	M	R5	B	40.4	29.9	40.4	1.30	0	96	37.8	35.6	35.2	36.3	35.4	35.6	5.8	3.5	2.14	319	149	2.3	4.9	0.013
S0	M	R7	B	37.4	31.9	37.4	1.30	0	104	37.8	35.5	36.0	36.0	36.2	35.9	5.9	4.4	2.14	341	160	1.5	1.5	0.009
S0	M	R7	B	33.6	29.6	33.6	1.30	0	86	37.8	34.6	34.9	35.0	33.5	34.6	5.5	3.9	2.14	208	97	1.6	-0.9	0.017
S0	M	R7	B	35.3	29.9	35.3	1.32	0	96	37.7	35.7	34.2	36.0	35.2	35.2	5.7	3.9	2.14	384	180	1.8	0.1	0.010
S0	M	R2	C	45.8	25.3	44.7	1.31	0	95	37.9	35.4	36.6	36.0	36.8	36.2	6.0	1.8	2.14	469	219	4.2	9.6	0.015
S0	M	R5	C	38.8	28.0	37.1	1.30	0	110	38.0	36.6	35.4	35.8	35.8	35.9	5.9	3.1	2.14	532	249	2.8	2.9	0.011
S0	M	R7	C	35.1	29.0	33.6	1.30	0	95	37.4	36.1	35.6	33.8	34.9	35.2	5.7	3.6	2.14	432	202	2.1	-0.1	0.010
S0	M	R2	D	44.6	24.8	44.6	1.30	0	112	37.7	35.5	36.0	36.6	36.4	36.0	5.9	1.8	2.14	356	167	4.1	8.6	0.019
S0	M	R5	D	39.6	29.4	39.6	1.33	0	95	37.7	35.5	35.9	34.8	35.9	35.6	5.8	3.4	2.14	325	152	2.4	4.1	0.014
S0	M	R5	D	37.2	27.9	37.2	1.30	0	93	37.7	35.4	34.2	35.6	33.4	34.7	5.5	3.1	2.14	308	144	2.4	2.5	0.015
S0	M	R7	D	33.6	28.0	32.6	1.30	0	102	38.0	36.7	35.9	36.5	33.9	35.9	5.9	3.4	2.14	423	198	2.5	-2.3	0.013
S0	M	R2	E	31.3	16.8	29.4	1.31	0	95	37.4	36.6	35.1	35.7	35.7	35.8	5.9	0.9	2.14	396	185	4.9	-4.5	0.031
S0	M	R5	E	29.3	22.0	28.0	1.31	0	95	37.4	36.3	36.2	35.2	33.8	35.5	5.8	2.2	2.14	448	210	3.6	-6.2	0.021
S0	M	R7	E	30.3	25.0	28.4	1.30	0	108	37.6	36.6	36.4	35.1	34.9	35.9	5.9	2.8	2.14	515	241	3.1	-5.6	0.015
S1	F	R2	A	51.6	28.0	51.6	1.34	0	153	37.8	35.1	36.7	36.5	40.4	36.9	6.2	2.2	1.54	156	101	4.0	14.7	0.022
S1	F	R5	A	41.0	30.1	41.0	1.33	0	126	38.0	35.2	35.6	35.8	36.3	35.7	5.8	3.5	1.54	186	121	2.3	5.3	0.015
S1	F	R7	A	35.2	30.0	35.2	1.34	0	134	37.7	35.8	36.1	35.9	35.9	35.9	5.9	3.9	1.54	216	140	2.0	-0.7	0.015
S1	F	R7	A	36.0	29.5	36.0	1.34	0	150	37.9	35.5	34.6	35.7	34.3	35.0	5.6	3.7	1.54	185	120	1.9	1.0	0.016
S1	F	R2	B	53.2	29.5	53.2	1.34	0	127	38.0	35.9	37.6	37.0	36.9	36.8	6.2	2.5	1.54	212	137	3.7	16.4	0.016
S1	F	R5	B	41.9	31.0	41.9	1.34	0	101	38.3	36.3	36.9	36.4	36.5	36.5	6.1	3.8	1.54	180	117	2.4	5.4	0.016
S1	F	R7	B	34.8	30.0	34.8	1.43	0	127	37.7	35.3	35.0	35.5	35.1	35.2	5.7	3.9	1.54	168	109	1.8	-0.4	0.017
S1	F	R2	C	51.5	24.0	49.8	1.36	1.5	125	38.0	36.6	37.6	37.3	37.0	37.1	6.3	1.1	1.54	260	168	5.2	14.4	0.021
S1	F	R5	C	43.2	30.5	42.0	1.34	0	139	37.9	36.1	36.6	36.9	37.4	36.6	6.2	3.5	1.54	186	121	2.6	6.6	0.017
S1	F	R7	C	36.1	29.8	36.1	1.34	0	127	37.7	34.9	35.2	35.9	35.6	35.3	5.7	3.8	1.54	210	136	1.9	0.8	0.014
S1	F	R2	D	49.6	24.5	49.6	1.40	0	137	38.1	37.5	37.0	39.0	38.0	37.8	6.5	1.4	1.54	166	108	5.1	11.9	0.030
S1	F	R5	D	39.1	29.9	39.1	1.34	0	114	38.0	36.4	36.6	36.7	35.7	36.3	6.1	3.6	1.54	209	135	2.4	2.8	0.016
S1	F	R7	D	34.8	29.1	34.8	1.34	0	114	38.1	35.5	35.7	35.6	35.6	35.6	5.8	3.7	1.54	152	98	2.2	-0.8	0.023
S1	F	R2	E	37.3	18.5	35.4	1.34	1.5	121	37.4	34.5	32.7	36.2	36.4	34.7	5.5	0.9	1.54	283	183	4.6	2.6	0.023
S1	F	R5	E	36.2	26.7	36.2	1.43	0	158	38.2	35.7	37.5	37.4	35.8	36.6	6.1	2.9	1.54	166	108	3.3	-0.4	0.031
S1	F	R7	E	32.0	26.0	30.0	1.36	1.5	142	37.8	34.9	35.0	35.6	34.6	35.0	5.6	3.0	1.54	276	179	2.7	-3.0	0.016

Experimental Data – Phase 1

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Tsk	Psk	Pv	BSA	Met	MSA	Psk-Pair	Tair-Tsk	ReT
S2	M	R2	A	51.0	28.0	49.3	1.21	0	110	37.9	36.3	35.7	35.9	39.2	36.6	6.1	2.2	2.08	246	118	3.9	14.4	0.020
S2	M	R5	A	40.5	30.4	40.2	1.31	0	112	37.5	36.0	35.3	35.7	35.8	35.7	5.8	3.7	2.08	281	135	2.2	4.8	0.013
S2	M	R7	A	39.6	30.9	38.7	1.27	0	109	37.7	36.6	35.5	36.1	34.6	35.7	5.9	3.9	2.08	275	132	2.0	3.9	0.013
S2	M	R2	B	51.0	28.8	51.0	1.18	0	100	38.0	35.6	36.8	37.3	38.5	36.9	6.2	2.5	2.08	305	147	3.8	14.1	0.017
S2	M	R5	B	43.5	30.5	42.9	1.19	0	109	37.7	36.1	35.7	36.0	36.3	36.0	5.9	3.5	2.08	263	127	2.4	7.5	0.015
S2	M	R7	B	36.8	31.0	35.6	1.17	0	109	38.0	36.8	35.8	35.3	35.4	35.9	5.9	4.1	2.08	354	170	1.8	0.9	0.010
S2	M	R2	C	45.1	25.3	45.1	1.20	0	96	37.6	36.2	36.2	36.4	36.1	36.2	6.0	1.9	2.08	262	126	4.1	8.9	0.023
S2	M	R5	C	41.5	30.0	40.7	1.19	0	114	37.8	36.8	36.4	36.5	39.8	37.2	6.3	3.5	2.08	306	147	2.9	4.3	0.017
S2	M	R7	C	36.5	30.0	35.4	1.28	0	102	37.6	35.9	35.8	35.8	35.6	35.8	5.9	3.8	2.08	294	141	2.1	0.7	0.014
S2	M	R2	D	49.5	24.0	48.5	1.28	0	113	37.9	36.8	36.8	36.3	36.0	36.5	6.1	1.3	2.08	287	138	4.8	13.0	0.023
S2	M	R5	D	36.7	26.2	36.7	1.20	0	109	37.2	36.2	35.3	35.6	35.1	35.6	5.8	2.7	2.08	252	121	3.1	1.1	0.024
S2	M	R7	D	38.5	31.3	37.2	1.24	0	111	37.9	36.8	36.8	36.3	38.3	37.0	6.3	4.1	2.08	276	133	2.2	1.5	0.015
S2	M	R2	E	32.4	18.5	32.2	1.19	0	102	37.8	36.7	36.5	36.3	36.5	36.5	6.1	1.2	2.08	273	131	4.9	-4.1	0.045
S2	M	R5	E	30.9	22.0	30.7	1.20	0	100	37.5	35.5	35.1	35.9	35.8	35.5	5.8	2.1	2.08	306	147	3.7	-4.6	0.031
S2	M	R7	E	32.2	26.1	31.6	1.19	0	122	37.9	37.0	37.0	36.7	37.2	37.0	6.3	3.0	2.08	285	137	3.3	-4.8	0.030
S3	M	R5	A	42.0	30.2	41.5	1.33	0	113	38.1	35.7	36.0	35.9	35.8	35.8	5.9	3.5	1.98	285	144	2.4	6.2	0.013
S3	M	R7	A	36.2	32.0	35.1	1.33	0	123	38.3	36.0	36.3	35.6	35.4	35.9	5.9	4.5	1.98	271	137	1.4	0.3	0.010
S3	M	R2	B	53.7	30.1	53.4	1.32	0	113	37.9	35.7	37.2	36.3	37.2	36.6	6.1	2.7	1.98	262	132	3.4	17.1	0.015
S3	M	R5	B	43.9	31.4	43.5	1.34	0	111	37.9	36.2	36.1	36.6	36.4	36.3	6.0	3.8	1.98	283	143	2.3	7.6	0.012
S3	M	R7	B	36.5	31.0	35.7	1.32	0	119	38.0	35.8	36.6	36.4	35.8	36.2	6.0	4.1	1.98	329	166	1.9	0.3	0.011
S3	M	R2	C	45.5	22.0	45.5	1.32	0	100	37.9	34.2	34.6	34.8	36.3	34.9	5.6	1.1	1.98	267	135	4.5	10.6	0.023
S3	M	R5	C	40.5	28.5	40.0	1.32	0	105	38.2	35.9	35.2	36.1	35.6	35.7	5.8	3.1	1.98	283	143	2.7	4.8	0.016
S3	M	R7	C	36.6	31.8	35.7	1.32	0	118	38.0	35.6	36.5	36.5	36.1	36.2	6.0	4.4	1.98	287	145	1.6	0.5	0.011
S3	M	R2	D	44.3	24.7	43.8	1.33	0	115	38.1	35.4	36.2	34.3	37.9	35.9	5.9	1.8	1.98	206	104	4.1	8.4	0.027
S3	M	R5	D	43.2	32.5	42.3	1.32	0	137	37.9	37.2	37.4	37.5	37.6	37.4	6.4	4.2	1.98	220	111	2.2	5.8	0.016
S3	M	R5	D	41.2	30.2	39.8	1.32	0	132	38.0	35.8	36.9	35.8	36.4	36.3	6.0	3.6	1.98	206	104	2.5	5.0	0.019
S3	M	R5	D	40.4	29.3	39.2	1.32	0	106	38.2	36.2	36.9	36.1	36.1	36.3	6.1	3.3	1.98	244	123	2.7	4.0	0.019
S3	M	R7	D	38.1	31.5	36.5	1.32	0	112	38.0	36.5	36.3	36.4	35.6	36.2	6.0	4.2	1.98	282	142	1.8	1.8	0.012
S3	M	R2	E	33.8	19.0	32.2	1.32	0	100	37.5	35.4	35.0	36.2	36.0	35.6	5.8	1.2	1.98	279	141	4.6	-1.8	0.035
S3	M	R5	E	30.0	22.0	29.0	1.34	0	93	37.5	34.3	33.8	35.1	33.5	34.2	5.4	2.1	1.98	293	148	3.3	-4.1	0.026
S3	M	R7	E	32.3	26.5	28.4	1.33	0	100	37.9	35.4	35.5	36.5	36.1	35.8	5.9	3.1	1.98	242	122	2.8	-3.5	0.027

Appendix B (Continued)

Experimental Data – Phase 1

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Tsk	Psk	Pv	BSA	Met	MSA	Psk-Pair	Tair-Tsk	ReT
S4	F	R2	A	46.8	25.8	45.4	1.20	0	116	37.5	36.4	36.7	36.7	36.2	36.5	6.1	1.9	1.59	142	89	4.2	10.3	0.029
S4	F	R5	A	41.2	30.2	40.3	1.20	0	136	38.0	35.7	37.1	35.5	35.7	36.1	6.0	3.6	1.59	184	116	2.4	5.1	0.017
S4	F	R7	A	38.2	31.5	38.2	1.19	0	130	37.8	36.3	35.7	36.5	36.2	36.2	6.0	4.2	1.59	235	148	1.8	2.1	0.011
S4	F	R2	B	47.7	25.8	46.9	1.19	0	132	38.1	35.0	37.9	36.6	38.0	36.8	6.2	1.9	1.59	134	84	4.3	10.9	0.030
S4	F	R5	B	42.2	31.1	41.1	1.20	0	124	38.0	36.2	37.7	36.3	36.9	36.8	6.2	3.8	1.59	166	104	2.4	5.4	0.018
S4	F	R7	B	41.1	32.0	39.7	1.20	0	135	38.2	36.8	38.0	36.7	37.0	37.2	6.3	4.1	1.59	149	94	2.2	3.9	0.019
S4	F	R2	C	48.3	26.7	47.3	1.20	0	123	37.6	36.2	37.2	36.6	36.8	36.7	6.2	2.1	1.59	135	85	4.1	11.6	0.028
S4	F	R5	C	46.9	27.4	46.7	1.20	0	129	37.6	35.4	37.1	35.9	36.9	36.3	6.1	2.3	1.59	118	74	3.7	10.6	0.028
S4	F	R7	C	35.1	29.2	33.7	1.20	0	127	37.7	35.8	35.1	35.8	34.6	35.4	5.7	3.7	1.59	122	77	2.1	-0.3	0.028
S4	F	R2	D	37.3	31.3	36.0	1.20	0	132	37.8	36.0	36.6	36.3	35.8	36.2	6.0	4.2	1.59	94	59	1.8	1.1	0.028
S4	F	R2	D	46.1	27.0	44.2	1.20	0	140	38.0	37.6	37.3	37.3	37.6	37.4	6.4	2.3	1.59	234	147	4.1	8.7	0.021
S4	F	R5	D	38.5	26.5	37.5	1.20	0	127	37.7	36.2	36.9	36.4	35.6	36.3	6.1	2.7	1.59	157	99	3.4	2.2	0.031
S4	F	R2	E	35.0	18.4	33.1	1.20	0	134	37.8	35.9	37.4	37.1	36.9	36.8	6.2	1.0	1.59	161	101	5.2	-1.8	0.057
S4	F	R5	E	35.4	24.0	33.7	1.19	0	130	37.7	34.9	37.0	36.8	36.3	36.2	6.0	2.2	1.59	192	121	3.8	-0.8	0.033
S4	F	R7	E	38.9	32.4	37.5	1.20	0	117	37.4	36.6	36.4	36.1	36.1	36.3	6.1	4.4	1.59	241	151	1.6	2.6	0.010
S5	F	R2	A	49.9	29.0	48.9	1.09	0	121	37.5	36.5	36.9	36.8	37.2	36.8	6.2	2.6	2.02	286	142	3.6	13.1	0.017
S5	F	R5	A	41.9	29.7	40.8	1.05	0	108	34.3	36.3	36.4	36.5	36.3	36.4	6.1	3.4	2.02	242	120	2.7	5.5	0.018
S5	F	R7	A	37.0	31.2	36.5	1.08	0	123	37.7	36.9	36.9	36.4	36.2	36.7	6.2	4.1	2.02	324	161	2.0	0.3	0.012
S5	F	R2	B	45.5	27.8	44.5	1.05	0	113	37.5	36.5	37.0	36.8	37.2	36.8	6.2	2.6	2.02	182	90	3.7	8.7	0.027
S5	F	R5	B	41.8	29.5	39.3	1.09	0	113	37.3	36.1	36.3	36.0	36.3	36.2	6.0	3.3	2.02	293	145	2.7	5.6	0.015
S5	F	R7	B	38.7	31.5	36.7	1.09	0	114	37.5	36.4	36.3	36.1	35.9	36.2	6.0	4.1	2.02	307	152	1.9	2.5	0.011
S5	F	R2	C	39.1	23.0	39.0	1.04	0	100	38.0	35.7	36.1	35.5	35.3	35.7	5.9	1.7	2.02	287	142	4.1	3.4	0.026
S5	F	R5	C	42.2	30.8	40.9	1.09	0	121	37.7	36.8	37.0	36.8	36.6	36.8	6.2	3.7	2.02	280	139	2.5	5.4	0.015
S5	F	R7	C	36.8	30.6	35.5	1.05	0	105	37.3	36.3	35.7	35.5	35.6	35.8	5.9	4.0	2.02	235	116	1.9	1.0	0.016
S5	F	R2	D	47.0	29.3	47.2	1.09	0	119	37.3	36.7	36.8	36.6	37.1	36.8	6.2	2.9	2.02	306	152	3.3	10.2	0.016
S5	F	R5	D	40.0	28.8	38.5	1.11	0	117	37.5	36.8	36.9	36.5	36.6	36.7	6.2	3.2	2.02	274	136	3.0	3.3	0.019
S5	F	R7	D	36.7	30.8	35.3	1.05	0	114	37.3	36.6	36.2	36.2	35.9	36.3	6.0	4.0	2.02	177	88	2.0	0.4	0.022
S5	F	R2	E	32.6	19.0	31.0	1.05	0	109	37.6	36.1	36.0	35.9	35.8	36.0	5.9	1.3	2.02	278	138	4.6	-3.4	0.039
S5	F	R5	E	32.8	23.5	31.6	1.09	0	107	37.4	35.9	36.0	36.2	36.0	36.0	5.9	2.3	2.02	275	136	3.7	-3.2	0.031
S5	F	R7	E	32.1	25.1	30.4	1.09	0	101	37.3	36.3	35.5	35.2	35.1	35.6	5.8	2.7	2.02	313	155	3.1	-3.5	0.023

Appendix B (Continued)

Experimental Data – Phase 1

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Tsk	Psk	Pv	BSA	Met	MSA	Psk-Pair	Tair-Tsk	ReT
S6	M	R2	A	51.3	27.3	50.2	1.12	0	92	37.6	35.8	36.8	36.7	37.2	36.6	6.1	2.0	2.28	369	162	4.1	14.7	0.017
S6	M	R5	A	43.4	31.3	41.9	1.13	0	96	37.5	36.4	35.9	36.0	36.0	36.1	6.0	3.7	2.28	299	131	2.2	7.3	0.013
S6	M	R7	A	40.9	33.3	39.6	1.11	0	115	37.9	36.7	36.7	36.5	36.7	36.6	6.2	4.6	2.28	397	174	1.6	4.3	0.008
S6	M	R2	B	48.9	25.5	48.0	1.13	0	90	36.7	35.0	35.9	36.3	35.8	35.7	5.8	1.7	2.28	437	192	4.1	13.2	0.016
S6	M	R5	B	45.2	33.0	44.1	1.13	0	96	37.7	36.3	36.3	36.4	37.1	36.5	6.1	4.2	2.28	310	136	1.9	8.7	0.010
S6	M	R7	B	42.0	34.5	39.3	1.11	0	112	38.1	37.1	36.9	36.6	36.9	36.9	6.2	5.0	2.28	396	174	1.3	5.1	0.006
S6	M	R2	C	49.6	26.5	48.4	1.13	0	95	37.6	36.1	36.1	36.3	37.0	36.3	6.0	1.9	2.28	333	146	4.1	13.3	0.019
S6	M	R5	C	41.4	29.5	39.9	1.12	0	91	37.5	36.3	36.2	36.1	36.3	36.2	6.0	3.3	2.28	357	157	2.7	5.2	0.014
S6	M	R7	C	37.6	31.0	36.2	1.13	0	90	37.5	36.0	36.0	35.9	35.8	36.0	5.9	4.1	2.28	363	160	1.9	1.6	0.011
S6	M	R7	C	41.0	33.0	39.2	1.16	0	97	37.4	36.2	36.2	36.3	36.5	36.3	6.0	4.5	2.28	361	159	1.5	4.7	0.008
S6	M	R2	D	46.3	25.0	44.8	1.13	0	102	37.5	36.6	36.7	36.4	37.1	36.7	6.2	1.7	2.28	426	187	4.4	9.6	0.018
S6	M	R5	D	39.1	27.0	37.9	1.13	0	88	37.6	36.4	35.4	35.9	35.5	35.8	5.9	2.8	2.28	358	157	3.1	3.3	0.018
S6	M	R7	D	36.6	30.0	35.5	1.12	0	104	37.6	36.6	36.1	36.3	36.2	36.3	6.0	3.8	2.28	367	161	2.2	0.2	0.014
S6	M	R2	E	34.4	18.0	32.4	1.12	0	84	37.4	34.7	36.0	36.0	36.0	35.6	5.8	1.0	2.28	377	166	4.8	-1.2	0.030
S6	M	R2	E	33.7	28.5	32.4	1.13	0	92	37.5	35.1	35.9	36.1	36.2	35.8	5.9	3.5	2.28	375	165	2.3	-2.1	0.015
S6	M	R5	E	33.9	25.0	32.1	1.16	0	85	37.5	35.7	36.1	35.8	33.9	35.5	5.8	2.6	2.28	408	179	3.2	-1.6	0.019
S7	F	R2	A	54.0	28.0	53.0	1.37	2	139	37.8	36.5	36.6	39.5	39.0	37.6	6.5	2.0	1.42	243	171	4.5	16.4	0.017
S7	F	R5	A	41.9	31.3	40.4	1.39	2	136	37.9	36.7	35.6	36.8	36.8	36.4	6.1	3.8	1.42	296	209	2.2	5.5	0.009
S7	F	R7	A	37.8	32.0	36.5	1.39	2	144	38.3	37.0	36.6	37.2	37.3	37.0	6.3	4.4	1.42	276	195	1.9	0.8	0.010
S7	F	R2	B	50.9	25.8	49.2	1.42	2	122	37.7	35.5	36.6	39.0	37.0	36.8	6.2	1.6	1.42	241	170	4.6	14.1	0.018
S7	F	R5	B	45.1	33.3	43.7	1.38	2	143	38.0	37.3	35.6	37.0	36.5	36.6	6.1	4.3	1.42	284	200	1.8	8.5	0.007
S7	F	R7	B	36.4	30.0	35.4	1.36	2	117	37.7	36.5	35.6	36.3	36.3	36.2	6.0	3.8	1.42	332	234	2.2	0.2	0.009
S7	F	R2	C	49.4	25.0	47.9	1.39	2	119	37.7	36.5	36.5	37.8	43.6	38.2	6.7	1.5	1.42	226	159	5.2	11.2	0.023
S7	F	R5	C	42.2	30.8	39.1	1.29	2	118	37.8	36.5	36.9	36.6	36.8	36.7	6.2	3.7	1.42	257	181	2.5	5.5	0.012
S7	F	R7	C	39.7	33.0	38.5	1.39	2	130	38.1	37.1	36.5	37.1	37.0	36.9	6.2	4.6	1.42	264	186	1.7	2.8	0.008
S7	F	R2	D	43.9	22.3	42.2	1.40	2	116	37.9	36.7	36.4	36.9	37.6	36.8	6.2	1.2	1.42	267	188	5.0	7.1	0.022
S7	F	R5	D	43.4	31.3	42.2	1.39	2	134	37.9	37.4	36.2	35.7	38.2	36.8	6.2	3.7	1.42	275	194	2.5	6.6	0.011
S7	F	R7	D	37.2	32.0	35.8	1.39	2	134	38.0	37.3	35.9	36.9	34.8	36.3	6.0	4.4	1.42	280	198	1.6	0.9	0.008
S7	F	R2	E	34.5	18.5	33.4	1.28	2	123	37.8	36.5	35.8	36.7	36.6	36.3	6.1	1.1	1.42	300	212	5.0	-1.9	0.025
S7	F	R5	E	34.0	25.0	32.3	1.39	2	113	37.6	36.5	37.1	37.0	36.4	36.8	6.2	2.6	1.42	264	186	3.6	-2.8	0.021
S7	F	R7	E	34.8	27.5	33.0	1.39	2	113	37.7	36.5	36.2	36.6	36.9	36.5	6.1	3.2	1.42	292	206	2.9	-1.7	0.015

Appendix B (Continued)

Experimental Data – Phase 1

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Tsk	Psk	Pv	BSA	Met	MSA	Psk-Pair	Tair-Tsk	ReT
S8	M	R2	A	52.5	30.0	50.8	1.02	0	128	37.7	35.7	36.8	36.3	38.0	36.6	6.1	2.7	2.48	323	130	3.4	15.9	0.016
S8	M	R5	A	45.4	33.5	44.3	1.01	0	146	37.6	36.9	36.6	36.2	36.0	36.5	6.1	4.4	2.48	430	174	1.7	8.9	0.008
S8	M	R7	A	42.3	35.5	41.1	1.01	0	141	37.9	36.9	38.2	37.5	36.9	37.4	6.4	5.3	2.48	431	174	1.1	4.9	0.005
S8	M	R2	B	52.4	27.8	51.1	1.03	0	124	37.4	35.7	36.0	36.2	37.9	36.3	6.0	2.1	2.48	449	181	3.9	16.0	0.015
S8	M	R5	B	45.0	33.5	44.0	1.02	0	146	37.5	36.8	36.8	36.5	37.4	36.8	6.2	4.4	2.48	425	172	1.8	8.2	0.008
S8	M	R7	B	39.0	30.5	37.7	1.00	0	121	37.5	35.4	35.2	36.0	34.5	35.3	5.7	3.8	2.48	440	178	1.9	3.7	0.010
S8	M	R2	C	55.0	29.0	58.9	1.03	0	137	37.7	36.9	36.0	37.4	36.0	36.5	6.1	2.3	2.48	466	188	3.9	18.5	0.013
S8	M	R5	C	41.0	31.0	39.9	1.02	0	109	37.1	35.4	34.9	36.1	36.1	35.5	5.8	3.8	2.48	422	170	2.0	5.5	0.010
S8	M	R7	C	38.7	31.5	37.5	1.01	0	131	37.5	37.2	36.0	36.2	36.4	36.5	6.1	4.1	2.48	427	172	2.0	2.2	0.011
S8	M	R2	D	48.6	26.0	47.0	1.03	0	132	37.8	36.8	37.2	36.9	36.4	36.9	6.2	1.9	2.48	483	195	4.4	11.7	0.017
S8	M	R5	D	43.4	31.5	42.1	1.02	0	129	37.6	36.7	34.5	36.4	36.0	35.8	5.9	3.8	2.48	432	174	2.1	7.6	0.010
S8	M	R7	D	37.9	32.0	36.9	1.02	0	118	37.3	36.3	36.0	36.8	36.0	36.3	6.0	4.4	2.48	457	185	1.7	1.7	0.009
S8	M	R2	E	32.0	17.3	31.1	1.03	0	104	37.0	34.8	34.9	35.6	36.1	35.2	5.7	1.0	2.48	397	160	4.7	-3.3	0.033
S8	M	R5	E	31.0	22.5	29.9	1.01	0	103	37.5	35.4	34.9	35.4	35.0	35.2	5.7	2.2	2.48	430	174	3.5	-4.2	0.023
S8	M	R7	E	34.6	28.0	33.5	1.01	0	126	37.4	34.1	36.3	36.2	34.6	35.3	5.7	3.3	2.48	419	169	2.4	-0.7	0.014
S8	M	R7	E	32.3	25.8	31.1	1.03	0	119	37.3	36.1	35.8	35.7	35.6	35.8	5.9	2.9	2.48	430	174	3.0	-3.5	0.020
S9	M	R2	A	51.1	27.0	49.9	1.03	0	87	37.3	36.2	35.7	36.7	37.5	36.4	6.1	2.0	2.38	391	165	4.1	14.7	0.017
S9	M	R5	A	42.3	31.0	41.4	1.03	0	108	37.6	36.4	36.4	36.3	37.0	36.5	6.1	3.7	2.38	356	150	2.4	5.8	0.013
S9	M	R7	A	38.3	31.0	36.6	1.03	0	99	37.6	36.7	36.0	37.5	36.6	36.6	6.1	4.0	2.38	377	159	2.1	1.7	0.013
S9	M	R2	B	37.4	25.0	36.3	1.03	0	85	37.0	36.4	36.6	36.7	37.3	36.7	6.2	2.3	2.38	375	158	3.8	0.7	0.024
S9	M	R5	B	41.2	31.5	40.0	1.03	0	102	37.4	36.6	36.6	36.1	36.7	36.5	6.1	4.0	2.38	351	148	2.1	4.7	0.012
S9	M	R2	C	53.9	28.0	52.5	1.04	0	101	37.5	37.5	36.8	37.1	37.8	37.3	6.4	2.0	2.38	342	144	4.3	16.6	0.018
S9	M	R5	C	43.8	32.3	42.4	1.04	0	105	38.0	37.2	37.0	36.7	37.0	37.0	6.3	4.1	2.38	376	158	2.2	6.8	0.011
S9	M	R7	C	37.4	31.5	36.1	1.06	0	107	37.7	38.1	35.9	36.5	36.3	36.8	6.2	4.2	2.38	383	161	2.0	0.6	0.012
S9	M	R2	D	43.4	24.0	41.6	1.03	0	89	37.3	37.1	36.6	36.1	36.6	36.7	6.2	1.7	2.38	365	154	4.5	6.7	0.023
S9	M	R5	D	38.8	29.5	38.5	1.04	0	97	38.2	36.4	36.6	36.6	36.5	36.5	6.1	3.5	2.38	340	143	2.6	2.3	0.017
S9	M	R7	D	36.3	30.5	35.0	1.04	0	101	37.6	36.6	35.9	36.7	35.4	36.2	6.0	4.0	2.38	345	145	2.0	0.1	0.014
S9	M	R2	E	33.1	18.0	31.6	1.03	0	95	37.1	36.1	36.1	36.2	36.2	36.1	6.0	1.1	2.38	411	173	4.9	-3.0	0.032
S9	M	R5	E	31.9	22.8	30.5	1.03	0	89	37.4	36.6	36.3	36.3	36.2	36.4	6.1	2.2	2.38	365	154	3.9	-4.5	0.030
S9	M	R7	E	31.6	25.0	30.8	1.03	0	87	37.0	36.3	35.9	36.1	36.1	36.1	6.0	2.7	2.38	370	156	3.2	-4.5	0.025

Appendix B (Continued)

Experimental Data – Phase 1

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Tsk	Psk	Pv	BSA	Met	MSA	Psk-Pair	Tair-Tsk	ReT
S10	M	R2	A	46.9	25.0	45.4	1.34	0	130	36.7	36.7	36.8	37.4	38.2	37.2	6.3	1.7	1.83	316	173	4.6	9.8	0.020
S10	M	R5	A	39.7	29.5	38.6	1.32	0	131	37.7	36.8	36.8	36.8	36.8	36.8	6.2	3.4	1.83	309	169	2.8	2.9	0.015
S10	M	R7	A	37.4	31.0	36.1	1.31	0	142	38.1	36.8	37.0	36.2	36.9	36.8	6.2	4.1	1.83	332	181	2.1	0.6	0.012
S10	M	R2	B	49.5	25.0	47.9	1.32	0	133	37.7	36.4	37.7	37.6	38.4	37.4	6.4	1.5	1.83	330	180	4.9	12.1	0.020
S10	M	R5	B	39.6	29.3	38.1	1.30	0	135	38.1	36.4	36.7	36.9	36.5	36.6	6.1	3.4	1.83	326	178	2.8	3.0	0.014
S10	M	R7	B	32.2	27.0	31.5	1.32	0	124	38.5	36.8	34.6	37.0	36.2	36.1	6.0	3.2	1.83	326	178	2.8	-3.9	0.018
S10	M	R2	C	46.4	23.5	45.4	1.34	0	136	37.9	36.6	37.0	37.3	38.4	37.2	6.3	1.4	1.83	301	164	5.0	9.2	0.023
S10	M	R5	C	39.5	28.8	37.8	1.31	0	131	37.8	36.5	36.9	37.2	37.5	36.9	6.3	3.2	1.83	281	153	3.0	2.6	0.018
S10	M	R7	C	37.3	30.8	35.9	1.31	0	125	37.7	36.3	36.1	36.6	36.7	36.4	6.1	4.0	1.83	323	176	2.1	0.8	0.011
S10	M	R2	D	43.6	22.5	42.3	1.31	0	132	37.7	36.6	36.8	36.3	37.1	36.7	6.2	1.3	1.83	321	175	4.9	6.9	0.023
S10	M	R5	D	37.7	27.0	36.5	1.32	0	129	37.8	36.8	36.4	36.7	37.0	36.7	6.2	2.9	1.83	320	175	3.3	1.0	0.018
S10	M	R7	D	36.6	29.0	35.2	1.32	0	146	38.4	38.1	37.2	37.3	37.0	37.5	6.4	3.5	1.83	321	175	2.9	-0.8	0.017
S10	M	R2	E	32.3	16.0	30.7	1.31	0	132	38.0	36.9	36.5	37.1	36.7	36.8	6.2	0.7	1.83	341	186	5.5	-4.5	0.034
S10	M	R5	E	32.8	22.5	31.0	1.32	0	128	37.8	36.8	35.2	36.8	36.0	36.2	6.0	2.0	1.83	329	180	4.0	-3.4	0.025
S10	M	R5	E	33.1	24.0	32.5	1.32	0	146	38.3	36.8	36.2	37.6	36.9	36.8	6.2	2.4	1.83	337	184	3.8	-3.7	0.023
S10	M	R7	E	33.2	27.0	31.8	1.24	0	133	38.0	36.5	36.1	36.4	36.5	36.4	6.1	3.2	1.83	286	156	2.9	-3.2	0.021
S11	M	R2	A	52.2	28.0	51.7	1.03	0	125	37.7	36.3	36.6	37.2	37.4	36.8	6.2	2.2	2.28	436	192	4.0	15.4	0.015
S11	M	R5	A	44.0	32.3	42.3	1.03	0	115	37.8	37.0	37.0	37.0	37.0	37.0	6.3	4.0	2.28	427	188	2.2	7.0	0.010
S11	M	R7	A	40.5	32.5	38.5	1.03	0	134	38.2	37.3	37.7	37.1	36.4	37.2	6.3	4.4	2.28	447	196	2.0	3.3	0.009
S11	M	R2	B	52.4	27.0	50.9	1.04	0	109	37.7	35.8	36.2	36.0	36.0	36.0	5.9	1.9	2.28	421	185	4.1	16.4	0.015
S11	M	R5	B	44.2	32.5	43.4	1.03	0	110	37.7	38.8	37.0	36.9	37.2	37.6	6.5	4.1	2.28	445	196	2.4	6.6	0.010
S11	M	R7	B	39.6	31.6	38.4	1.03	0	110	37.8	37.2	36.8	36.6	36.5	36.8	6.2	4.1	2.28	417	183	2.1	2.8	0.011
S11	M	R2	C	52.1	26.0	49.9	1.03	0	103	37.6	36.4	36.3	37.1	37.7	36.8	6.2	1.6	2.28	390	171	4.6	15.3	0.018
S11	M	R5	C	42.4	31.0	41.4	1.07	0	110	37.7	36.0	35.3	36.3	36.7	36.0	5.9	3.7	2.28	459	202	2.2	6.4	0.009
S11	M	R7	C	36.8	29.8	36.5	1.03	0	118	37.9	37.2	36.3	36.3	35.8	36.5	6.1	3.7	2.28	418	184	2.4	0.3	0.013
S11	M	R2	D	47.4	25.5	46.4	1.03	0	128	37.9	37.3	36.9	37.3	37.5	37.2	6.4	1.8	2.28	418	184	4.6	10.1	0.019
S11	M	R5	D	40.4	29.3	38.9	1.03	0	112	37.4	36.4	36.7	35.1	36.3	36.2	6.0	3.3	2.28	394	173	2.7	4.2	0.014
S11	M	R7	D	36.1	29.3	34.6	1.03	0	105	37.6	36.5	37.4	36.3	36.4	36.7	6.2	3.6	2.28	366	161	2.6	-0.7	0.016
S11	M	R2	E	36.0	19.0	34.7	1.02	0	117	37.8	36.9	37.4	37.3	37.1	37.2	6.3	1.1	2.28	385	169	5.3	-1.2	0.032
S11	M	R5	E	30.9	23.5	29.8	1.02	0	117	37.9	36.9	36.9	36.6	36.7	36.8	6.2	2.4	2.28	415	182	3.8	-5.9	0.026
S11	M	R7	E	32.4	27.0	31.0	1.02	0	119	37.6	36.8	36.8	36.7	36.6	36.8	6.2	3.2	2.28	388	170	3.0	-4.4	0.020

Appendix B (Continued)

Experimental Data – Phase 1

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Tsk	Psk	Pv	BSA	Met	MSA	Psk-Pair	Tair-Tsk	ReT
S12	M	R2	A	52.7	26.0	51.2	1.08	0	104	37.3	35.4	37.0	37.0	37.0	36.5	6.1	1.6	2.18	316	145	4.5	16.2	0.019
S12	M	R5	A	43.1	31.0	41.7	1.07	0	119	37.8	36.7	37.0	36.9	36.6	36.8	6.2	3.7	2.18	323	148	2.5	6.3	0.014
S12	M	R7	A	37.7	31.0	36.5	1.09	0	105	37.3	35.4	35.6	36.2	35.2	35.6	5.8	4.0	2.18	306	140	1.8	2.1	0.012
S12	M	R2	B	53.7	28.0	52.3	1.08	0	113	37.5	36.5	36.5	36.6	38.0	36.8	6.2	2.1	2.18	302	138	4.2	16.9	0.018
S12	M	R5	B	42.1	30.5	39.9	1.05	0	122	37.5	35.6	34.9	36.3	34.8	35.4	5.7	3.6	2.18	151	69	2.1	6.7	0.020
S12	M	R5	B	43.1	33.0	42.0	1.08	0	103	37.6	36.7	36.8	36.7	36.7	36.7	6.2	4.4	2.18	304	139	1.8	6.4	0.010
S12	M	R7	B	38.6	31.5	36.5	1.07	0	110	37.8	36.3	36.1	36.5	35.3	36.1	6.0	4.2	2.18	296	136	1.8	2.5	0.012
S12	M	R2	C	53.9	27.9	52.8	1.07	0	116	37.7	36.3	36.2	36.9	38.1	36.8	6.2	2.0	2.18	333	152	4.2	17.1	0.017
S12	M	R5	C	42.1	30.0	40.2	1.07	0	110	37.5	36.6	36.5	36.6	36.7	36.6	6.1	3.4	2.18	310	142	2.7	5.5	0.016
S12	M	R7	C	39.3	32.0	37.6	1.07	0	105	37.7	36.2	36.3	36.7	36.5	36.4	6.1	4.3	2.18	306	140	1.8	2.9	0.011
S12	M	R2	D	45.4	22.5	44.0	1.07	0	115	37.4	36.4	36.7	37.0	36.3	36.6	6.1	1.2	2.18	306	140	4.9	8.8	0.026
S12	M	R5	D	38.7	28.5	37.5	1.07	0	105	37.8	36.6	36.5	36.8	36.4	36.6	6.1	3.2	2.18	316	145	2.9	2.1	0.019
S12	M	R5	D	40.3	33.5	38.8	1.09	0	121	37.5	35.5	37.2	37.4	37.3	36.7	6.2	4.7	2.18	319	146	1.5	3.6	0.009
S12	M	R7	D	36.0	29.0	34.5	1.06	0	109	37.9	36.4	36.0	36.2	35.2	36.0	5.9	3.5	2.18	333	152	2.4	0.0	0.016
S12	M	R2	E	33.4	17.0	32.2	1.08	0	97	37.3	35.6	36.0	36.5	36.1	36.0	5.9	0.8	2.18	317	145	5.1	-2.6	0.039
S12	M	R5	E	30.5	23.0	30.0	1.08	0	99	37.6	36.2	35.9	35.9	36.2	36.1	6.0	2.3	2.18	325	149	3.6	-5.6	0.031
S12	M	R7	E	32.8	26.5	32.0	1.07	0	103	37.2	36.3	36.2	35.7	35.7	36.0	6.0	3.0	2.18	300	137	2.9	-3.2	0.024
S13	F	R2	A	56.2	28.5	54.5	1.27	0	132	38.3	36.5	37.5	37.5	37.5	37.2	6.3	2.0	1.71	312	182	4.3	19.0	0.015
S13	F	R5	A	43.7	33.0	42.3	1.28	0	122	38.4	36.9	36.9	38.4	37.5	37.3	6.4	4.3	1.71	263	154	2.1	6.4	0.011
S13	F	R7	A	40.3	33.8	38.8	1.28	0	143	38.6	36.9	36.7	36.8	37.3	36.9	6.3	4.8	1.71	320	187	1.4	3.4	0.007
S13	F	R2	B	54.9	27.0	53.1	1.27	0	118	37.9	36.8	37.0	37.6	38.6	37.4	6.4	1.7	1.71	308	180	4.7	17.5	0.017
S13	F	R5	B	45.8	34.0	44.4	1.27	0	128	38.3	37.1	37.3	37.1	37.7	37.3	6.4	4.5	1.71	289	169	1.8	8.5	0.009
S13	F	R7	B	38.2	31.0	36.4	1.28	0	126	38.7	35.9	36.0	36.2	35.1	35.8	5.9	4.0	1.71	323	189	1.9	2.4	0.009
S13	F	R2	C	54.0	28.0	51.6	1.27	0	120	38.1	36.4	37.2	37.8	38.1	37.3	6.4	2.0	1.71	264	154	4.3	16.7	0.017
S13	F	R5	C	41.8	30.0	40.4	1.28	0	122	38.2	37.8	35.9	37.1	38.0	37.1	6.3	3.5	1.71	305	178	2.9	4.7	0.014
S13	F	R7	C	38.8	31.5	37.2	1.27	0	117	38.2	36.2	35.0	36.4	36.6	36.0	5.9	4.1	1.71	288	168	1.8	2.8	0.010
S13	F	R2	D	48.5	26.0	47.0	1.28	0	118	38.1	37.2	36.3	36.9	37.2	36.9	6.2	1.9	1.71	294	172	4.4	11.6	0.019
S13	F	R5	D	38.1	28.5	36.8	1.28	0	123	38.0	37.1	36.7	36.2	36.1	36.6	6.1	3.3	1.71	332	194	2.9	1.5	0.014
S13	F	R7	D	40.4	33.0	38.0	1.28	0	118	38.1	36.9	36.4	36.8	36.9	36.7	6.2	4.5	1.71	294	172	1.7	3.7	0.009
S13	F	R2	E	37.5	19.5	35.7	1.28	0	112	38.1	35.9	36.8	36.8	37.1	36.6	6.1	1.1	1.71	316	184	5.1	0.9	0.027
S13	F	R2	E	39.9	20.5	38.4	1.25	0	127	38.3	37.4	37.7	38.0	38.0	37.7	6.5	1.1	1.71	314	183	5.4	2.2	0.028
S13	F	R5	E	36.0	25.0	34.4	1.28	0	123	38.2	36.1	36.6	36.7	36.8	36.5	6.1	2.4	1.71	310	181	3.7	-0.5	0.021
S13	F	R7	E	32.7	27.0	31.4	1.28	0	113	38.2	36.6	36.5	36.2	36.0	36.4	6.1	3.2	1.71	321	187	2.9	-3.7	0.017

APPENDIX C

EXPERIMENTAL DATA – PHASE 2

Appendix C

Experimental Data – Phase 2: Data Dictionary

Title	**Description**
Code	Participant Code
Gender	Gender of participant
Proto	Protocol Design: Metabolic Demand (M1 (80 W/m^2), M2 (160 W/m^2), M3 (240 W/m^2))
Ens	Ensemble: (A (work clothes), B (cotton coveralls), C (particle barrier), D (liquid barrier), E (vapor barrier))
Tdb	Ambient air temperature (dry bulb) in degrees Celsius
Tpwb	Wet bulb air temperature in degrees Celsius
Tg	Black bulb air temperature in degrees Celsius
S(m/s)	Speed in meters per second
G(%)	Grade of treadmill in percentage
HR	Heart rate
Tre	Body core temperature (rectal)
Tch	Skin temperature at the chest
Tarm	Skin temperature at the upper arm
Tth	Skin temperature at the thigh
Tcalf	Skin temperature at the calf
Met	Calculated metabolic work based on O2 consumption in Watts
BSA	Body surface area in square meters
MSA	Met divided by the BSA (W/m^2)
Tsk	Average Skin temperature
Psk	Partial pressure of the water vapor at the skin
Pv	Partial pressure of the water vapor in the air
Psk-Pv	ΔP: Difference between Psk and Pv
Tair-Tsk	ΔT: Difference between Tdb and Tsk
ReT	Total evaporative resistance

Appendix C (Continued)

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
1	F	M1	A	44.90	34.00	43.20	0.43	0.0	86	37.06	36.27	35.95	36.56	36.83	170	1.55	110	36.34	6.05	4.59	1.5	8.6	0.009
1	F	M2	A	40.10	29.25	38.60	1.35	1.5	120	37.80	37.66	37.66	35.44	35.21	208	1.55	134	36.73	6.18	3.33	2.8	3.4	0.018
1	F	M3	A	35.80	26.75	34.65	1.66	4.5	124	37.51	34.96	34.71	34.93	33.84	384	1.55	248	34.66	5.51	2.91	2.6	1.1	0.010
1	F	M1	B	45.40	34.00	43.10	0.41	0.0	86	37.81	37.32	36.76	37.43	36.84	98	1.55	63	37.08	6.30	4.55	1.7	8.3	0.016
1	F	M2	B	42.00	31.50	40.50	1.35	0.0	136	37.81	35.09	35.69	35.77	35.62	250	1.55	161	35.51	5.78	3.92	1.9	6.5	0.009
1	F	M3	B	36.40	26.50	34.25	1.66	4.5	150	37.71	32.96	32.84	33.88	33.49	309	1.55	199	33.21	5.09	2.80	2.3	3.2	0.010
1	F	M1	C	44.00	30.75	43.10	0.41	0.0	104	37.20	35.76	36.15	36.52	36.41	128	1.55	83	36.16	5.99	3.54	2.5	7.8	0.019
1	F	M2	C	40.20	29.00	38.60	1.39	1.5	119	37.56	34.56	34.55	34.99	34.79	257	1.55	166	34.69	5.52	3.25	2.3	5.5	0.011
1	F	M3	C	33.30	23.00	31.40	1.67	4.5	150	38.11	33.42	31.92	33.41	34.70	376	1.55	243	33.22	5.09	2.12	3.0	0.1	0.012
1	F	M1	D	43.80	31.50	41.40	0.43	0.0	89	37.09	35.84	36.05	36.00	35.84	121	1.55	78	35.94	5.92	3.80	2.1	7.9	0.017
1	F	M2	D	37.90	28.00	36.20	1.50	1.5	111	37.28	35.81	35.88	35.07	35.53	297	1.55	192	35.63	5.82	3.11	2.7	2.3	0.013
1	F	M3	D	35.10	26.00	32.90	1.70	4.5	110	37.74	34.78	35.68	35.16	35.21	384	1.55	248	35.21	5.69	2.75	2.9	-0.1	0.012
1	F	M1	E	39.40	29.00	37.40	0.28	0.0	108	37.65	36.54	37.25	36.82	37.40	116	1.55	75	36.98	6.27	3.31	3.0	2.4	0.033
1	F	M2	E	33.10	19.00	31.10	1.40	1.5	141	38.17	34.89	35.44	36.71	34.56	279	1.55	180	35.35	5.73	1.25	4.5	-2.3	0.027
1	F	M3	E	29.50	21.00	27.10	1.70	4.5	172	38.35	33.68	33.05	34.35	33.69	385	1.55	248	33.63	5.21	1.92	3.3	-4.1	0.015
2	M	M1	A	46.10	34.00	43.95	0.38	0.0	123	37.36	36.27	36.74	36.46	37.31	222	2.19	101	36.66	6.16	4.51	1.6	9.4	0.010
2	M	M2	A	41.60	30.00	38.80	1.14	0.0	120	37.80	36.07	36.13	36.30	36.08	396	2.19	181	36.14	5.98	3.46	2.5	5.5	0.012
2	M	M3	A	42.40	31.00	40.20	1.59	1.0	131	38.33	35.96	36.57	36.43	36.28	506	2.19	231	36.30	6.04	3.73	2.3	6.1	0.008
2	M	M2	B	40.40	31.00	39.20	1.15	0.0	113	37.46	35.64	36.43	32.28	36.13	385	2.19	176	35.30	5.71	3.86	1.9	5.1	0.009
2	M	M1	C	42.80	32.00	41.15	0.37	0.0	111	37.63	36.57	36.83	37.58	36.47	191	2.19	87	36.83	6.21	4.03	2.2	6.0	0.018
2	M	M2	C	44.40	33.00	42.15	1.07	0.0	117	37.74	36.87	36.61	36.49	37.26	399	2.19	182	36.79	6.20	4.26	1.9	7.6	0.008
2	M	M3	C	39.10	29.00	38.40	1.55	1.0	122	38.24	36.41	35.54	36.09	34.33	459	2.19	210	35.67	5.83	3.33	2.5	3.4	0.011
2	M	M1	D	42.10	32.50	41.00	0.27	0.0	127	37.51	36.60	37.05	36.58	36.99	235	2.19	107	36.81	6.21	4.25	2.0	5.3	0.014
2	M	M2	D	39.50	28.00	38.00	1.10	0.0	120	38.00	35.75	36.20	36.35	36.28	335	2.19	153	36.11	5.97	3.01	3.0	3.4	0.017
2	M	M3	D	38.80	29.00	37.85	1.63	0.0	127	38.29	35.34	35.08	36.53	35.69	474	2.19	216	35.57	5.80	3.35	2.5	3.2	0.010
2	M	M2	E	35.50	25.50	33.80	1.09	0.0	101	37.36	36.54	36.50	36.37	36.56	310	2.19	142	36.50	6.10	2.59	3.5	-1.0	0.026
2	M	M3	E	31.60	21.75	29.80	1.63	0.0	126	38.05	35.79	36.32	36.37	35.87	478	2.19	218	36.08	5.96	1.94	4.0	-4.5	0.022

Appendix C (Continued)

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
3	F	M1	A	45.20	34.50	44.00	0.38	0.0	106	37.57	36.68	36.74	37.40	36.94	249	2.02	123	36.89	6.24	4.75	1.5	8.3	0.009
3	F	M2	A	41.60	31.00	40.20	1.21	0.0	128	37.91	36.48	36.89	36.28	36.60	351	2.02	174	36.59	6.13	3.78	2.4	5.0	0.011
3	F	M3	A	35.30	27.00	35.20	1.45	1.5	140	38.10	36.00	36.00	36.10	35.00	505	2.02	250	35.82	5.88	3.01	2.9	-0.5	0.012
3	F	M1	B	43.50	32.50	41.60	0.38	0.0	116	37.51	36.64	36.33	36.47	36.59	240	2.02	119	36.50	6.10	4.15	2.0	7.0	0.012
3	F	M2	B	40.50	29.00	38.60	1.12	0.0	116	37.63	35.56	36.38	36.04	36.14	318	2.02	157	36.02	5.94	3.23	2.7	4.5	0.015
3	F	M3	B	37.10	26.10	35.60	1.51	1.0	142	38.07	35.50	36.66	36.09	35.73	503	2.02	249	36.01	5.94	2.64	3.3	1.1	0.013
3	F	M1	C	44.90	33.30	43.40	0.38	0.0	114	37.49	37.18	37.17	36.59	36.93	221	2.02	109	37.01	6.27	4.34	1.9	7.9	0.013
3	F	M2	C	40.50	29.50	38.90	1.12	0.0	113	37.61	36.38	35.45	36.02	36.19	328	2.02	162	35.99	5.94	3.38	2.6	4.5	0.013
3	F	M3	C	36.40	27.50	35.80	1.45	1.5	138	38.08	36.49	36.61	34.55	35.45	540	2.02	267	35.93	5.92	3.07	2.8	0.5	0.011
3	F	M1	D	40.00	30.50	39.00	0.38	0.0	112	37.52	36.14	36.66	36.13	35.93	234	2.02	116	36.25	6.02	3.73	2.3	3.7	0.017
3	F	M2	D	38.10	28.00	36.50	1.11	0.0	118	38.00	36.38	36.69	36.34	35.76	341	2.02	169	36.34	6.05	3.10	2.9	1.8	0.016
3	F	M3	D	33.90	24.50	31.70	1.54	1.0	131	37.85	35.58	35.14	34.92	34.73	453	2.02	224	35.15	5.67	2.44	3.2	-1.2	0.015
3	F	M1	E	36.60	27.50	35.30	0.38	0.0	136	38.05	36.94	37.52	37.11	37.12	232	2.02	115	37.18	6.33	3.06	3.3	-0.6	0.029
3	F	M2	E	35.50	26.00	33.35	1.07	0.0	117	37.65	35.61	36.16	35.18	36.41	275	2.02	136	35.85	5.89	2.72	3.2	-0.3	0.024
3	F	M3	E	31.50	22.00	29.10	1.56	1.0	138	38.42	35.93	36.21	36.39	35.78	442	2.02	219	36.08	5.96	2.01	4.0	-4.6	0.021
4	M	M1	A	44.80	32.00	42.90	0.47	0.0	95	37.62	36.14	36.51	35.87	35.81	290	2.15	135	36.13	5.98	3.89	2.1	8.7	0.011
4	M	M2	A	40.40	30.70	39.30	1.26	0.0	105	38.10	35.27	36.10	35.91	35.47	441	2.15	205	35.69	5.84	3.76	2.1	4.7	0.009
4	M	M3	A	38.20	28.40	36.40	1.48	1.0	95	37.99	35.86	34.67	34.46	34.02	465	2.15	216	34.86	5.58	3.21	2.4	3.3	0.010
4	M	M1	B	46.40	34.00	43.90	0.35	0.0	96	37.44	36.55	36.09	37.12	37.29	263	2.15	122	36.67	6.16	4.49	1.7	9.7	0.010
4	M	M2	B	40.60	29.80	39.10	1.22	0.0	93	37.86	37.01	36.16	34.81	35.53	411	2.15	191	36.02	5.94	3.47	2.5	4.6	0.011
4	M	M3	B	34.40	24.50	32.60	1.66	1.0	100	37.84	34.12	34.65	32.67	33.93	282	2.15	131	33.95	5.30	2.41	2.9	0.4	0.022
4	M	M1	C	44.90	33.30	43.40	0.69	0.0	87	37.23	36.02	36.44	36.17	37.00	215	2.15	100	36.37	6.06	4.34	1.7	8.5	0.012
4	M	M2	C	39.90	29.50	38.50	1.26	0.0	95	37.76	35.37	34.71	35.25	35.60	444	2.15	207	35.19	5.68	3.42	2.3	4.7	0.010
4	M	M3	C	36.30	26.00	34.80	1.60	1.0	108	38.17	35.21	34.22	34.01	35.15	587	2.15	273	34.66	5.52	2.67	2.8	1.6	0.010
4	M	M1	D	41.00	30.60	39.40	0.36	0.0	95	37.78	36.34	36.68	35.86	36.11	243	2.15	113	36.30	6.04	3.69	2.3	4.7	0.017
4	M	M2	D	41.40	30.60	39.20	1.18	0.0	121	38.14	36.56	36.81	35.74	35.22	398	2.15	185	36.20	6.00	3.67	2.3	5.2	0.011
4	M	M3	D	38.70	26.00	37.00	1.58	1.0	122	38.28	35.21	36.14	34.98	34.77	591	2.15	275	35.36	5.73	2.51	3.2	3.3	0.011
4	M	M1	E	36.40	26.80	34.90	0.34	0.0	90	37.74	36.92	36.78	36.18	36.59	257	2.15	120	36.66	6.16	2.88	3.3	-0.3	0.028
4	M	M2	E	29.90	22.90	28.50	1.27	0.0	95	37.82	35.76	36.27	32.29	35.51	464	2.15	216	35.17	5.67	2.32	3.4	-5.3	0.018
4	M	M3	E	28.20	20.20	26.70	1.52	1.0	111	37.91	35.43	35.52	35.72	34.74	561	2.15	261	35.38	5.74	1.83	3.9	-7.2	0.019

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
5	M	M1	A	42.10	30.60	40.40	0.35	0.0	103	37.71	35.49	36.54	35.39	35.25	286	2.13	134	35.74	5.85	3.62	2.2	6.4	0.013
5	M	M2	A	39.50	28.10	37.40	1.15	0.0	110	37.88	35.88	36.23	36.42	35.69	388	2.13	182	36.06	5.96	3.04	2.9	3.4	0.014
5	M	M3	A	37.50	27.00	36.20	1.44	1.0	112	37.51	33.03	35.51	34.83	34.98	477	2.13	224	34.52	5.47	2.86	2.6	3.0	0.011
5	M	M1	B	42.50	31.00	40.70	0.39	0.0	102	37.19	36.23	36.53	36.00	36.37	289	2.13	136	36.30	6.04	3.72	2.3	6.2	0.014
5	M	M2	B	41.30	30.30	40.00	1.04	0.0	106	37.51	35.39	36.06	35.52	35.97	406	2.13	191	35.73	5.85	3.58	2.3	5.6	0.010
5	M	M3	B	38.50	28.35	36.95	1.44	1.0	110	37.88	34.96	35.90	35.36	35.60	476	2.13	223	35.45	5.76	3.18	2.6	3.1	0.011
5	M	M1	C	42.60	32.40	41.50	0.39	0.0	121	37.69	36.19	37.29	36.39	36.44	252	2.13	118	36.61	6.14	4.18	2.0	6.0	0.013
5	M	M2	C	40.20	29.70	39.10	1.04	0.0	110	37.81	36.27	36.76	36.18	36.35	377	2.13	177	36.42	6.07	3.47	2.6	3.8	0.013
5	M	M3	C	35.60	26.60	34.30	1.34	1.0	105	37.33	34.91	34.74	34.66	34.11	453	2.13	213	34.65	5.51	2.88	2.6	1.0	0.012
5	M	M1	D	42.00	30.80	40.50	0.39	0.0	111	37.44	36.00	36.77	36.46	36.77	249	2.13	117	36.48	6.10	3.69	2.4	5.5	0.016
5	M	M2	D	36.50	26.00	35.10	1.05	0.0	107	37.57	35.16	35.64	35.89	35.26	374	2.13	176	35.47	5.77	2.66	3.1	1.0	0.017
5	M	M3	D	33.70	23.80	32.20	1.44	1.0	108	37.46	34.84	35.97	35.10	34.49	489	2.13	230	35.16	5.67	2.28	3.4	-1.5	0.015
5	M	M1	E	34.90	24.90	33.30	0.40	0.0	113	37.95	36.28	36.78	36.45	36.25	272	2.13	128	36.46	6.09	2.48	3.6	-1.6	0.030
5	M	M2	E	34.20	25.80	33.30	1.04	0.0	115	37.47	36.26	37.32	36.65	36.58	356	2.13	167	36.72	6.18	2.76	3.4	-2.5	0.023
5	M	M3	E	27.80	20.60	25.95	1.45	1.0	130	37.50	35.91	36.39	35.81	34.44	525	2.13	246	35.74	5.85	1.94	3.9	-7.9	0.021
6	M	M1	A	43.70	32.35	42.40	0.39	0.0	82	37.59	36.14	36.19	36.31	36.39	241	2.03	119	36.24	6.02	4.09	1.9	7.5	0.012
6	M	M2	A	38.50	28.90	37.10	1.18	0.0	73	37.50	34.86	35.56	35.78	35.49	364	2.03	179	35.38	5.74	3.34	2.4	3.1	0.012
6	M	M3	A	40.30	28.60	38.30	1.63	1.0	91	37.35	35.29	35.88	36.17	35.99	511	2.03	252	35.78	5.87	3.13	2.7	4.5	0.010
6	M	M1	B	43.10	31.20	41.40	0.38	0.0	74	37.19	35.52	36.28	34.19	35.87	229	2.03	113	35.55	5.79	3.74	2.0	7.5	0.013
6	M	M2	B	40.10	30.00	38.10	1.13	0.0	85	37.16	36.65	35.95	35.56	35.66	347	2.03	171	36.02	5.95	3.56	2.4	4.1	0.012
6	M	M3	B	41.40	30.50	40.10	1.59	1.0	102	37.77	35.87	36.26	37.11	36.48	503	2.03	248	36.36	6.06	3.63	2.4	5.0	0.009
6	M	M1	C	43.20	31.00	41.30	0.39	0.0	73	37.01	36.43	36.60	35.74	35.99	227	2.03	112	36.26	6.02	3.67	2.3	6.9	0.016
6	M	M2	C	42.10	30.80	40.10	1.17	0.0	90	37.20	36.08	35.71	36.03	36.47	323	2.03	159	36.04	5.95	3.68	2.3	6.1	0.011
6	M	M3	C	36.60	27.50	36.10	1.58	1.0	93	37.85	35.81	36.05	35.07	35.39	415	2.03	204	35.65	5.82	3.06	2.8	0.9	0.013
6	M	M1	D	42.60	30.90	41.20	0.39	0.0	78	37.37	36.50	37.23	36.34	36.85	251	2.03	124	36.76	6.19	3.68	2.5	5.8	0.016
6	M	M2	D	38.90	27.60	37.00	1.18	0.0	88	37.33	36.12	36.60	36.28	35.71	361	2.03	178	36.21	6.01	2.93	3.1	2.7	0.016
6	M	M3	D	37.30	26.20	34.80	1.57	1.0	103	37.86	36.11	35.93	35.65	34.67	578	2.03	285	35.68	5.83	2.66	3.2	1.6	0.011
6	M	M1	E	38.40	28.20	36.80	0.39	0.0	75	37.69	36.77	36.96	36.93	37.19	247	2.03	122	36.94	6.25	3.14	3.1	1.5	0.024
6	M	M2	E	33.60	23.40	31.00	1.17	0.0	90	37.13	35.98	36.27	36.03	35.57	341	2.03	168	36.00	5.94	2.19	3.7	-2.4	0.025
6	M	M3	E	28.50	20.20	26.65	1.61	1.0	103	37.34	35.28	35.55	35.47	35.86	513	2.03	253	35.52	5.78	1.81	4.0	-7.0	0.020

Appendix C (Continued)

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
7	M	M1	A	42.10	31.90	40.90	0.39	0.0	100	37.39	35.80	35.50	35.06	35.87	230	1.93	119	35.58	5.80	4.04	1.8	6.5	0.011
7	M	M2	A	40.70	29.95	39.45	1.18	1.0	103	37.72	35.78	36.62	35.92	36.41	343	1.93	178	36.19	6.00	3.51	2.5	4.5	0.012
7	M	M3	A	38.00	28.40	37.20	1.63	2.0	109	38.15	35.57	35.62	35.59	36.01	507	1.93	263	35.68	5.83	3.22	2.6	2.3	0.009
7	M	M1	B	41.40	30.70	39.50	0.40	0.0	96	37.17	35.76	35.98	35.22	35.77	268	1.93	139	35.72	5.85	3.70	2.2	5.7	0.013
7	M	M2	B	43.00	31.70	41.60	1.18	1.0	116	37.62	36.31	36.41	36.42	36.53	339	1.93	176	36.41	6.07	3.92	2.2	6.6	0.010
7	M	M3	B	37.60	27.70	36.00	1.62	2.0	105	37.53	34.72	36.61	36.20	35.11	636	1.93	330	35.66	5.83	3.05	2.8	1.9	0.008
7	M	M1	C	43.20	32.10	41.45	0.39	0.0	112	37.31	36.22	36.23	35.79	35.71	220	1.93	114	36.04	5.95	4.04	1.9	7.2	0.012
7	M	M1	C	43.80	32.30	41.80	0.40	0.0	101	37.14	36.63	36.54	35.83	35.79	255	1.93	132	36.28	6.03	4.06	2.0	7.5	0.011
7	M	M2	C	41.70	30.35	39.75	1.18	1.0	107	37.63	36.43	37.54	36.24	36.19	363	1.93	188	36.68	6.16	3.57	2.6	5.0	0.012
7	M	M3	C	38.50	27.60	36.80	1.58	2.0	125	37.87	35.16	36.79	35.93	35.15	542	1.93	281	35.80	5.87	2.96	2.9	2.7	0.010
7	M	M1	D	42.00	30.80	40.35	0.40	0.0	107	37.83	36.79	37.14	36.17	36.56	202	1.93	105	36.73	6.18	3.69	2.5	5.3	0.019
7	M	M2	D	40.10	29.15	38.10	1.18	1.0	110	37.67	36.37	37.12	36.76	36.29	339	1.93	176	36.66	6.16	3.30	2.9	3.4	0.014
7	M	M3	D	35.60	24.75	33.80	1.63	2.0	109	37.67	33.81	35.28	35.43	36.22	592	1.93	307	35.06	5.64	2.39	3.2	0.5	0.010
7	M	M1	E	37.30	28.40	36.10	0.40	0.0	106	37.51	36.00	36.50	36.70	36.00	221	1.93	115	36.29	6.03	3.27	2.8	1.0	0.023
7	M	M2	E	34.50	25.00	33.00	1.18	1.0	122	38.07	33.43	37.32	36.94	37.18	335	1.93	174	36.05	5.95	2.53	3.4	-1.5	0.021
7	M	M3	E	26.10	18.65	25.20	1.64	2.0	113	37.92	34.97	35.51	34.76	35.79	497	1.93	258	35.25	5.70	1.65	4.0	-9.2	0.021
8	M	M2	A	43.20	30.95	41.60	0.41	0.0	118	37.52	36.80	36.67	36.84	37.38	176	1.93	91	36.89	6.23	3.66	2.6	6.3	0.019
8	M	M2	A	39.00	28.60	37.80	1.31	0.0	130	38.06	36.12	36.72	35.86	36.48	276	1.68	164	36.32	6.04	3.22	2.8	2.7	0.015
8	M	M3	A	38.00	27.65	36.30	1.58	3.0	159	38.29	36.24	37.39	35.83	35.11	416	1.68	248	36.28	6.03	3.01	3.0	1.7	0.012
8	M	M1	B	41.90	30.20	40.60	0.42	0.0	115	37.21	34.96	36.83	36.03	36.65	171	1.68	102	36.07	5.96	3.51	2.5	5.8	0.018
8	M	M2	B	39.10	28.70	37.80	1.30	0.0	122	37.48	36.07	35.89	35.46	35.29	306	1.68	182	35.74	5.85	3.24	2.6	3.4	0.013
8	M	M3	B	37.50	26.65	35.70	1.64	2.0	146	37.96	36.00	36.37	34.77	36.12	447	1.68	266	35.89	5.90	2.76	3.1	1.6	0.011
8	M	M1	C	37.80	28.00	37.00	0.41	0.0	101	36.90	36.31	35.08	35.06	36.62	171	1.68	102	35.75	5.86	3.12	2.7	2.0	0.024
8	M	M2	C	39.90	29.00	38.60	1.30	0.0	134	37.83	36.49	36.17	35.82	36.76	314	1.68	187	36.31	6.04	3.27	2.8	3.6	0.013
8	M	M3	C	38.60	26.95	36.35	1.65	2.0	145	37.80	35.39	36.38	35.26	36.10	404	1.68	240	35.80	5.87	2.77	3.1	2.8	0.012
8	M	M1	D	40.10	29.00	38.10	0.41	0.0	109	37.42	36.62	36.95	36.05	36.63	172	1.68	102	36.61	6.14	3.26	2.9	3.5	0.024
8	M	M2	D	36.70	26.00	35.50	1.31	0.0	119	37.39	35.91	35.03	36.07	35.70	270	1.68	161	35.64	5.82	2.64	3.2	1.1	0.019
8	M	M3	D	35.20	23.80	33.10	1.64	2.0	161	38.44	36.81	37.08	35.77	35.84	408	1.68	243	36.49	6.10	2.18	3.9	-1.3	0.017
8	M	M1	E	33.80	25.00	33.00	0.41	0.0	117	37.64	36.73	37.11	36.74	36.99	206	1.68	123	36.90	6.24	2.58	3.7	-3.1	0.035
8	M	M2	E	31.00	21.90	28.60	1.32	0.0	140	37.92	35.94	37.88	36.90	36.45	334	1.68	199	36.82	6.21	2.02	4.2	-5.8	0.026
8	M	M3	E	29.90	21.05	28.05	1.62	2.0	135	38.00	35.39	35.31	36.10	36.57	360	1.68	214	35.74	5.86	1.90	4.0	-5.8	0.023

Appendix C (Continued)

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
9	M	M1	A	43.30	32.40	41.40	0.39	0.0	119	37.95	36.44	36.92	36.40	35.54	343	1.69	203	36.40	6.07	4.13	1.9	6.9	0.008
9	M	M2	A	40.80	30.25	39.70	1.22	0.0	117	37.79	35.99	36.40	36.52	35.69	359	1.69	212	36.16	5.99	3.60	2.4	4.6	0.010
9	M	M3	A	36.00	26.50	34.80	1.69	1.0	133	38.05	35.42	35.88	36.54	36.27	520	1.69	308	35.95	5.92	2.82	3.1	0.0	0.010
9	M	M2	B	42.60	31.00	41.00	1.22	0.0	120	37.91	36.31	37.71	36.00	36.12	331	1.69	196	36.63	6.15	3.71	2.4	6.0	0.010
9	M	M3	B	40.60	29.20	38.50	1.55	2.5	123	37.90	36.06	36.93	35.13	36.30	487	1.69	288	36.18	6.00	3.29	2.7	4.4	0.009
9	M	M1	C	46.30	33.05	44.60	0.40	0.0	142	38.07	37.14	37.33	36.81	36.81	243	1.69	144	37.07	6.29	4.15	2.1	9.2	0.011
9	M	M2	C	43.10	30.60	41.20	1.23	0.0	120	37.88	36.94	37.27	36.77	36.05	372	1.69	220	36.83	6.21	3.55	2.7	6.3	0.010
9	M	M3	C	41.70	29.90	39.90	1.56	2.0	139	38.22	36.76	38.40	35.96	34.97	520	1.69	308	36.73	6.18	3.43	2.8	5.0	0.008
9	M	M1	D	42.20	30.80	40.50	0.39	0.0	132	38.07	37.26	37.92	36.61	36.92	252	1.69	149	37.26	6.36	3.68	2.7	4.9	0.015
9	M	M2	D	39.40	28.60	37.30	1.22	0.0	114	37.84	35.73	36.65	36.62	36.73	339	1.69	201	36.38	6.06	3.19	2.9	3.0	0.013
9	M	M3	D	35.70	26.00	34.20	1.54	2.0	130	37.98	36.28	36.26	34.22	35.61	527	1.69	312	35.73	5.85	2.71	3.1	0.0	0.010
9	M	M1	E	35.90	26.30	34.70	0.40	0.0	133	38.05	36.25	37.87	36.77	37.13	278	1.69	164	37.02	6.28	2.78	3.5	-1.1	0.022
9	M	M2	E	35.30	25.80	34.10	1.22	0.0	137	38.26	35.60	38.67	37.25	36.66	363	1.69	215	37.06	6.29	2.68	3.6	-1.8	0.018
9	M	M3	E	32.80	24.20	31.40	1.63	2.0	139	38.26	35.56	37.09	36.24	35.83	634	1.69	375	36.21	6.01	2.44	3.6	-3.4	0.010
10	M	M1	A	45.00	33.30	43.45	0.39	0.0	108	37.76	37.17	36.94	36.55	36.94	231	2.02	114	36.93	6.25	4.33	1.9	8.1	0.012
10	M	M2	A	39.30	28.80	38.50	1.18	0.5	109	37.64	35.67	36.69	35.59	36.08	385	2.02	191	36.04	5.95	3.25	2.7	3.3	0.013
10	M	M3	A	35.90	26.00	34.00	1.55	2.5	141	38.45	38.01	36.39	35.56	35.27	656	2.02	325	36.49	6.10	2.70	3.4	-0.6	0.011
10	M	M1	B	46.50	34.40	44.50	0.40	0.0	99	37.57	37.20	36.99	36.78	36.32	224	2.02	111	36.88	6.23	4.63	1.6	9.6	0.010
10	M	M2	B	38.80	28.00	36.60	1.18	0.5	116	37.71	35.12	37.75	35.45	37.81	410	2.02	203	36.51	6.11	3.05	3.1	2.3	0.014
10	M	M3	B	36.60	25.60	34.80	1.50	3.0	122	37.97	35.54	36.32	35.45	35.16	534	2.02	264	35.68	5.83	2.54	3.3	0.9	0.012
10	M	M1	C	43.50	30.80	41.90	0.39	0.0	97	37.46	36.67	37.38	36.34	36.46	215	2.02	106	36.78	6.20	3.59	2.6	6.7	0.018
10	M	M2	C	39.00	28.60	36.90	1.18	0.5	101	37.84	35.89	36.00	36.11	35.61	345	2.02	171	35.91	5.91	3.22	2.7	3.1	0.014
10	M	M3	C	38.60	27.00	36.50	1.50	3.0	129	38.16	35.23	36.29	35.40	34.24	586	2.02	290	35.38	5.74	2.79	3.0	3.2	0.009
10	M	M1	D	41.30	30.30	39.40	0.40	0.0	93	37.38	36.82	38.05	36.00	36.33	260	2.02	129	36.93	6.25	3.58	2.7	4.4	0.017
10	M	M2	D	37.00	27.50	36.20	1.18	0.5	110	37.61	36.68	37.39	36.51	36.92	372	2.02	184	36.91	6.24	3.03	3.2	0.1	0.017
10	M	M3	D	39.20	27.50	37.40	1.55	2.5	141	38.14	36.12	37.19	36.07	35.03	542	2.02	268	36.21	6.01	2.89	3.1	3.0	0.011
10	M	M1	E	40.60	29.00	38.20	0.38	0.0	104	37.54	37.15	37.71	37.05	36.89	235	2.02	116	37.25	6.36	3.23	3.1	3.4	0.023
10	M	M2	E	32.50	24.90	31.00	1.18	0.5	124	37.94	38.65	36.29	36.71	36.57	384	2.02	190	37.14	6.32	2.64	3.7	-4.6	0.023
10	M	M3	E	26.60	19.90	27.20	1.55	2.5	140	38.53	36.82	37.45	35.87	36.33	592	2.02	293	36.72	6.18	1.87	4.3	-10.1	0.020

Appendix C (Continued)

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
11	F	M1	A	44.80	32.10	43.20	0.41	0.0	106	37.38	36.64	36.99	35.18	37.25	181	1.66	109	36.58	6.13	3.93	2.2	8.2	0.014
11	F	M2	A	40.50	29.60	38.60	1.28	1.0	119	37.38	36.34	35.51	36.07	35.89	295	1.66	178	35.95	5.92	3.41	2.5	4.6	0.012
11	F	M3	A	37.70	27.80	36.80	1.56	4.5	38	37.73	35.67	36.35	35.95	35.83	399	1.66	240	35.96	5.93	3.07	2.9	1.7	0.011
11	F	M1	B	42.50	31.80	41.20	0.40	0.0	97	37.39	37.43	36.74	36.57	36.71	165	1.66	99	36.91	6.24	3.98	2.3	5.6	0.017
11	F	M2	B	42.30	31.00	40.50	1.27	1.0	116	37.57	36.96	38.31	36.67	36.90	260	1.66	157	37.30	6.37	3.73	2.6	5.0	0.014
11	F	M3	B	36.80	26.50	34.60	1.62	3.5	136	37.78	35.47	35.51	34.41	34.57	371	1.66	223	35.09	5.65	2.77	2.9	1.7	0.012
11	F	M1	C	43.50	31.90	42.30	0.41	0.0	107	37.49	36.54	37.79	36.28	34.22	160	1.66	96	36.40	6.07	3.95	2.1	7.1	0.016
11	F	M2	C	41.10	29.60	39.10	1.27	1.0	119	37.39	36.34	35.96	35.44	36.45	260	1.66	157	36.07	5.96	3.37	2.6	5.0	0.014
11	F	M3	C	36.30	27.10	34.60	1.64	3.5	125	37.59	35.06	35.90	35.71	35.49	369	1.66	222	35.53	5.79	2.97	2.8	0.8	0.012
11	F	M1	D	44.60	32.45	42.55	0.41	0.0	117	37.41	36.79	38.42	36.99	37.64	194	1.66	117	37.49	6.44	4.06	2.4	7.1	0.015
11	F	M2	D	40.50	28.40	38.90	1.27	1.0	119	37.90	37.33	36.95	36.81	36.85	301	1.66	181	37.02	6.28	3.06	3.2	3.5	0.016
11	F	M3	D	34.60	25.90	33.60	1.42	4.5	129	37.36	34.93	35.52	35.55	35.16	439	1.66	264	35.28	5.71	2.76	2.9	-0.7	0.011
11	F	M1	E	35.60	26.00	33.60	0.41	0.0	93	37.11	36.62	36.65	36.32	36.17	167	1.66	101	36.48	6.10	2.72	3.4	-0.9	0.035
11	F	M2	E	35.30	24.70	33.00	1.28	1.0	119	37.72	36.57	38.39	37.00	36.94	231	1.66	139	37.28	6.37	2.40	4.0	-2.0	0.031
11	F	M3	E	31.50	22.00	30.80	1.55	4.5	115	37.27	36.81	36.54	36.34	35.54	351	1.66	211	36.38	6.06	2.01	4.1	-4.9	0.023
12	F	M1	A	44.10	32.40	42.40	0.55	0.0	135	37.70	36.51	36.79	36.65	37.53	157	1.57	100	36.83	6.21	4.08	2.1	7.3	0.015
12	F	M3	A	38.00	27.20	36.60	1.56	4.0	182	38.05	37.04	35.80	35.68	35.54	392	1.57	250	36.10	5.97	2.88	3.1	1.9	0.012
12	F	M1	B	44.70	32.55	43.00	0.55	0.0	135	37.68	37.69	37.07	37.27	37.47	170	1.57	108	37.38	6.40	4.09	2.3	7.3	0.016
12	F	M1	B	41.50	30.20	39.70	1.37	0.0	149	37.93	36.38	36.84	36.27	36.54	307	1.57	196	36.53	6.11	3.53	2.6	5.0	0.012
12	F	M3	B	40.50	28.75	38.50	1.50	4.0	171	38.06	35.63	36.71	34.41	35.42	365	1.57	232	35.67	5.83	3.16	2.7	4.8	0.010
12	F	M1	C	44.00	33.50	42.70	0.54	0.0	146	37.90	36.16	37.52	36.76	37.43	160	1.57	102	36.94	6.25	4.47	1.8	7.1	0.013
12	F	M2	C	41.90	30.10	39.90	1.37	0.0	156	38.21	36.57	36.91	36.08	36.70	299	1.57	190	36.60	6.14	3.47	2.7	5.3	0.012
12	F	M3	C	38.20	27.30	36.65	1.49	4.0	164	38.34	36.11	36.21	36.41	36.12	472	1.57	301	36.20	6.00	2.90	3.1	2.0	0.010
12	F	M1	D	41.80	29.70	40.50	0.54	0.0	142	37.70	36.85	38.57	36.32	37.05	105	1.57	67	37.30	6.37	3.36	3.0	4.5	0.033
12	F	M2	D	39.20	28.90	37.70	1.38	0.0	165	38.26	37.89	35.22	34.74	36.21	290	1.57	185	36.12	5.98	3.29	2.7	3.1	0.013
12	F	M3	D	34.20	25.20	32.80	1.56	4.0	145	37.86	35.95	33.33	34.84	35.16	404	1.57	257	34.78	5.55	2.60	3.0	-0.6	0.012
12	F	M1	E	35.50	26.10	34.20	0.54	0.0	164	38.01	39.84	35.75	37.02	37.07	174	1.57	111	37.50	6.44	2.75	3.7	-2.0	0.037
12	F	M1	E	41.90	29.90	40.00	0.55	0.0	151	37.98	37.18	37.83	37.55	37.85	152	1.57	97	37.58	6.47	3.41	3.1	4.3	0.025
12	F	M2	E	31.50	22.70	29.70	1.37	0.0	154	38.08	41.23	37.18	35.81	35.90	306	1.57	195	37.87	6.57	2.17	4.4	-6.4	0.029
12	F	M3	E	30.90	19.50	29.80	1.32	6.0	149	38.06	35.65	32.96	35.92	35.46	384	1.57	245	34.86	5.58	1.50	4.1	-4.0	0.019
12	F	M3	E	33.90	24.80	33.70	1.46	4.5	172	38.26	35.98	36.88	36.83	36.08	369	1.57	235	36.44	6.08	2.52	3.6	-2.5	0.016

Appendix C (Continued)

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
13	M	M1	A	45.90	34.40	43.80	0.38	0.0	117	37.38	37.21	36.51	36.12	36.58	210	2.06	102	36.66	6.16	4.67	1.5	9.2	0.009
13	M	M2	A	46.10	32.90	44.50	1.21	0.0	156	37.91	37.37	37.55	37.37	37.55	476	2.06	231	37.46	6.43	4.12	2.3	8.6	0.008
13	M	M3	A	36.20	26.40	35.20	1.44	3.0	147	38.13	35.76	35.83	35.99	34.40	445	2.06	216	35.56	5.79	2.78	3.0	0.6	0.014
13	M	M1	B	43.90	31.60	42.10	0.38	0.0	126	37.54	36.29	37.03	35.42	35.36	209	2.06	101	36.15	5.99	3.82	2.2	7.7	0.015
13	M	M2	B	42.10	30.70	40.20	1.21	0.0	132	38.10	36.19	38.66	36.43	36.27	354	2.06	172	37.00	6.27	3.65	2.6	5.1	0.013
13	M	M3	B	40.40	27.90	38.50	1.49	2.5	144	37.98	34.64	35.47	34.76	35.00	441	2.06	214	34.99	5.62	2.92	2.7	5.4	0.011
13	M	M1	C	46.30	34.20	44.10	0.39	0.0	129	37.84	37.58	37.17	37.19	37.33	233	2.06	113	37.33	6.38	4.57	1.8	9.0	0.011
13	M	M2	C	42.10	31.10	41.50	1.21	0.0	137	37.86	35.75	38.22	36.17	35.86	335	2.06	163	36.60	6.14	3.78	2.4	5.5	0.012
13	M	M3	C	36.90	26.40	34.70	1.49	2.5	132	38.16	35.04	35.32	35.39	34.46	463	2.06	225	35.08	5.64	2.74	2.9	1.8	0.012
13	M	M1	D	41.30	31.20	40.20	0.38	0.0	120	37.50	37.05	36.75	36.37	36.42	244	2.06	118	36.70	6.17	3.87	2.3	4.6	0.016
13	M	M2	D	37.70	26.90	35.90	1.19	0.0	125	37.66	35.82	36.29	35.59	35.47	356	2.06	173	35.85	5.89	2.82	3.1	1.9	0.017
13	M	M3	D	35.90	26.30	34.00	1.50	2.5	164	38.84	36.26	36.51	36.00	36.27	557	2.06	270	36.29	6.03	2.78	3.3	-0.4	0.012
13	M	M1	E	37.50	27.50	35.90	0.36	0.0	110	37.31	37.09	36.91	36.84	36.98	211	2.06	102	36.96	6.26	3.00	3.3	0.5	0.031
13	M	M2	E	33.70	24.00	32.00	1.22	0.0	136	38.05	36.28	37.16	36.80	36.54	354	2.06	172	36.70	6.17	2.33	3.8	-3.0	0.025
13	M	M3	E	29.10	20.85	27.20	1.49	2.5	138	38.53	33.51	35.38	35.64	34.79	507	2.06	246	34.75	5.54	1.91	3.6	-5.7	0.018
15	M	M1	A	45.50	33.40	44.20	0.63	0.0	113	37.44	36.46	36.94	36.73	36.37	211	1.8	117	36.64	6.15	4.33	1.8	8.9	0.011
15	M	M2	A	41.40	30.80	40.20	1.14	1.5	118	37.68	36.91	36.08	36.44	36.84	285	1.8	158	36.55	6.12	3.73	2.4	4.8	0.012
15	M	M3	A	36.80	26.50	35.50	1.42	4.5	116	37.78	35.65	35.95	34.64	36.06	476	1.8	264	35.62	5.82	2.77	3.0	1.2	0.011
15	M	M1	B	44.70	32.80	44.00	0.63	0.0	109	37.15	36.50	36.35	36.09	36.10	221	1.8	123	36.29	6.03	4.17	1.9	8.4	0.011
15	M	M2	B	41.50	29.80	39.80	1.14	1.5	118	37.82	36.60	36.44	35.41	36.06	318	1.8	177	36.21	6.01	3.41	2.6	5.3	0.012
15	M	M3	B	40.00	28.80	37.70	1.42	4.5	135	38.19	35.84	35.57	35.79	35.06	467	1.8	259	35.59	5.81	3.21	2.6	4.4	0.009
15	M	M1	C	42.00	29.70	40.30	0.64	0.0	99	37.39	36.69	36.77	36.31	37.07	222	1.8	123	36.71	6.17	3.34	2.8	5.3	0.018
15	M	M2	C	42.80	31.60	41.45	1.14	1.5	116	37.84	36.71	36.68	36.04	36.49	298	1.8	166	36.52	6.11	3.90	2.2	6.3	0.011
15	M	M3	C	39.00	27.80	37.50	1.42	4.5	135	37.83	35.93	36.27	36.10	34.76	484	1.8	269	35.83	5.88	2.98	2.9	3.2	0.010
15	M	M1	D	42.90	30.60	41.80	0.63	0.0	112	37.62	36.94	36.59	36.51	36.57	223	1.8	124	36.68	6.16	3.57	2.6	6.2	0.016
15	M	M2	D	39.00	28.10	37.20	1.13	1.5	110	37.56	36.39	35.72	36.44	36.09	332	1.8	184	36.14	5.98	3.07	2.9	2.9	0.014
15	M	M3	D	36.20	25.50	34.70	1.42	4.5	128	37.73	35.96	36.26	35.26	35.44	466	1.8	259	35.81	5.88	2.54	3.3	0.4	0.013
15	M	M1	E	37.40	28.00	37.00	0.64	0.0	103	37.31	37.00	37.00	37.00	37.10	188	1.8	104	37.02	6.28	3.15	3.1	0.4	0.029
15	M	M2	E	36.00	26.10	34.60	1.14	1.5	116	37.31	36.37	36.01	36.64	36.50	301	1.8	167	36.34	6.05	2.72	3.3	-0.3	0.020
15	M	M3	E	32.30	22.00	30.50	1.42	4.5	133	37.65	36.46	36.65	36.26	36.46	453	1.8	252	36.48	6.10	1.95	4.1	-4.2	0.019

Appendix C (Continued)

Experimental Data – Phase 2

Code	Gender	Proto	Ens	Tdb	Tpwb	Tg	S(m/s)	G (%)	HR	Tre	Tch	Tarm	Tth	Tcalf	Met	BSA	MSA	Tsk	Psk	Pv	Psk-Pair	Tair-Tsk	R_{eT}
16	M	M1	A	45.90	33.40	44.80	0.34	0.0	109	37.34	36.52	36.14	36.40	36.37	223	2.11	106	36.35	6.05	4.30	1.7	9.5	0.011
16	M	M2	A	43.20	31.40	41.50	1.22	0.0	113	37.83	36.77	36.00	36.24	36.26	346	2.11	164	36.33	6.05	3.80	2.2	6.9	0.011
16	M	M3	A	41.50	30.50	40.20	1.40	2.5	126	38.02	35.72	35.51	36.21	36.79	469	2.11	222	35.97	5.93	3.63	2.3	5.5	0.009
16	M	M1	B	44.40	32.10	42.50	0.38	0.0	108	37.56	36.48	36.31	35.79	36.12	240	2.11	114	36.22	6.01	3.96	2.1	8.2	0.013
16	M	M2	B	41.40	30.00	39.40	1.22	0.0	110	37.53	36.22	36.46	36.09	36.29	341	2.11	162	36.28	6.03	3.48	2.6	5.1	0.013
16	M	M3	B	38.20	29.10	36.80	1.36	3.5	127	38.09	35.83	35.91	35.44	35.79	511	2.11	242	35.77	5.86	3.42	2.4	2.4	0.009
16	M	M1	C	44.90	32.80	43.30	0.38	0.0	122	37.71	36.77	36.32	36.40	36.75	192	2.11	91	36.56	6.12	4.16	2.0	8.3	0.014
16	M	M2	C	39.30	27.90	37.20	1.21	0.0	128	38.67	35.67	35.78	34.81	36.25	354	2.11	168	35.65	5.82	2.99	2.8	3.7	0.015
16	M	M3	C	40.50	28.90	39.30	1.35	3.5	124	37.75	36.79	36.15	35.29	35.48	450	2.11	213	36.04	5.95	3.20	2.7	4.5	0.011
16	M	M1	D	42.90	30.40	40.90	0.34	0.0	121	37.79	39.97	36.36	36.40	36.69	204	2.11	97	37.52	6.45	3.50	2.9	5.4	0.023
16	M	M2	D	38.50	29.30	37.50	1.21	0.0	101	37.72	36.31	36.10	36.22	36.42	340	2.11	161	36.25	6.02	3.46	2.6	2.2	0.015
16	M	M3	D	37.70	25.80	36.00	1.36	3.5	135	37.90	36.71	35.73	35.76	36.31	468	2.11	222	36.15	5.99	2.52	3.5	1.6	0.015
16	M	M1	E	39.10	29.60	38.00	0.37	0.0	119	37.98	37.30	36.22	37.13	37.45	266	2.11	126	36.97	6.26	3.51	2.8	2.1	0.020
16	M	M1	E	39.90	28.50	38.60	0.38	0.0	116	37.43	36.99	37.26	36.93	37.23	204	2.11	97	37.11	6.31	3.13	3.2	2.8	0.028
16	M	M2	E	32.00	25.80	32.00	1.16	0.0	119	38.28	37.05	36.84	36.72	36.87	377	2.11	179	36.89	6.23	2.90	3.3	-4.9	0.023
16	M	M3	E	33.10	24.80	31.20	1.35	3.5	136	37.83	36.71	36.12	36.63	36.28	485	2.11	230	36.43	6.08	2.57	3.5	-3.3	0.017
16	M	M3	E	35.20	25.20	33.30	1.26	4.5	139	37.85	36.17	36.87	35.80	36.73	467	2.11	221	36.42	6.08	2.53	3.5	-1.2	0.017

APPENDIX D

SAS CODE AND ANALYSIS – PHASE 1

Appendix D

SAS Code – Phase 1

```
options nodate nonumber;
libname Vc 'F:\USF\NIOSH Studies\evap res Yr1\';

* SAS Code for Analyzing Re,T for Phase 1;

%macro mean1 (var1, var2, var3, var4);
Proc Means data=Vc.ret n mean var std stddev;
      title "SAS Analysis of Phase 1 Data";
      Class &var2 &var3 &var4;
      var &var1;
Run;
%mend;
%mean1 (ReT, ensemble);
%mean1 (ReT, ensemble, proto);
%mean1 (ReT, proto);

%macro anov1 (var1, var2, var3, var4);
Proc glm data=vc.ret;
      title "Three way ANOVA using Proc GLM for &var1 Data";
      Class &var2 &var3 &var4;
      Model &var1 = &var2 &var3 &var4;
      lsmeans &var2 &var3 &var4 /pdiff adjust=Tukey alpha=0.05;
      run;
%mend;
%anov1 (ReT, ensemble, proto, subj);

%macro anov2 (var1, var2, var3, var4);
Proc glm data=vc.ret;
      title "Three-way ANOVA of &var1 data set: Testing Interaction of
&var2 x &var3";
      Class &var2 &var3 &var4;
      Model &var1 = &var2 | &var3 &var4;
      *lsmeans &var2 | &var3 /pdiff adjust=Tukey alpha=0.05;
      run;
%mend;
%anov2 (ReT, ensemble, proto, subj);

%macro mixed1 (var1, var2, var3, var4);
Proc mixed data=vc.ret;
      title "Analysis of $var1 using the Mixed Model";
      Class &var2 &var3 &var4;
      Model &var1 = &var2 &var3;
      Random &var4;
      LSmeans &var2 &var3 /adjust=tukey alpha=.05;
      run;
%mend;
%mixed1 (ReT, ensemble, proto, subj);
```

Appendix D (Continued)

SAS Analysis – Phase 1

SAS Analysis of Phase 1 Data

The MEANS Procedure

Analysis Variable : ReT ReT

Ensemble	Obs	N	Mean	Variance	Std Dev
A	42	42	0.0139524	0.000019656	0.0044335
B	44	44	0.0143409	0.000026044	0.0051033
C	43	43	0.0158140	0.000031060	0.0055731
D	46	46	0.0178696	0.000030649	0.0055362
E	45	45	0.0265333	0.000076118	0.0087246

Appendix D (Continued)

SAS Analysis – Phase 1

SAS Analysis of Phase 1 Data

The MEANS Procedure

Analysis Variable : ReT ReT

Ensemble	Proto	Obs	N	Mean	Variance	Std Dev
A	R2	13	13	0.0183846	0.000014923	0.0038630
	R5	14	14	0.0128571	8.2857143E-6	0.0028785
	R7	15	15	0.0111333	9.1238095E-6	0.0030206
B	R2	14	14	0.0187857	0.000023258	0.0048227
	R5	15	15	0.0126000	0.000013971	0.0037378
	R7	15	15	0.0119333	0.000015210	0.0038999
C	R2	14	14	0.0202857	0.000018220	0.0042685
	R5	14	14	0.0148571	0.000022440	0.0047370
	R7	15	15	0.0125333	0.000022981	0.0047938
D	R2	15	15	0.0220667	0.000017781	0.0042167
	R5	18	18	0.0168333	0.000026147	0.0051134
	R7	13	13	0.0144615	0.000020936	0.0045756
E	R2	16	16	0.0328125	0.000090696	0.0095234
	R5	15	15	0.0261333	0.000021981	0.0046884
	R7	14	14	0.0197857	0.000031566	0.0056184

Appendix D (Continued)

SAS Analysis – Phase 1

SAS Analysis of Phase 1 Data

The MEANS Procedure

Analysis Variable : ReT ReT

Proto	Obs	N	Mean	Variance	Std Dev
R2	72	72	0.0228056	0.000063483	0.0079676
R5	76	76	0.0167368	0.000042516	0.0065205
R7	72	72	0.0138750	0.000028364	0.0053258

Appendix D (Continued)

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure

Class Level Information

Class	Levels	Values
Ensemble	5	A B C D E
Proto	3	R2 R5 R7
Subj	14	S0 S1 S10 S11 S12 S13 S2 S3 S4 S5 S6 S7 S8 S9

Number of observations 220

Appendix D (Continued)

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure

Dependent Variable: ReT ReT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	0.00962095	0.00050637	32.80	<.0001
Error	200	0.00308801	0.00001544		
Corrected Total	219	0.01270896			

R-Square	Coeff Var	Root MSE	ReT Mean
0.757021	22.09211	0.003929	0.017786

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00475024	0.00118756	76.91	<.0001
Proto	2	0.00273468	0.00136734	88.56	<.0001
Subj	13	0.00213603	0.00016431	10.64	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00455585	0.00113896	73.77	<.0001
Proto	2	0.00261372	0.00130686	84.64	<.0001
Subj	13	0.00213603	0.00016431	10.64	<.0001

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Ensemble	ReT LSMEAN	LSMEAN Number
A	0.01412073	1
B	0.01452913	2
C	0.01597198	3
D	0.01778303	4
E	0.02648958	5

Least Squares Means for effect Ensemble
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3	4	5
1		0.9891	0.1958	0.0002	<.0001
2	0.9891		0.4312	0.0012	<.0001
3	0.1958	0.4312		0.1972	<.0001
4	0.0002	0.0012	0.1972		<.0001
5	<.0001	<.0001	<.0001	<.0001	

Appendix D (Continued)

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Proto	LSMEAN ReT LSMEAN	Number
R2	0.02250895	1
R5	0.01663240	2
R7	0.01419533	3

Least Squares Means for effect Proto
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3
1		<.0001	<.0001
2	<.0001		0.0007
3	<.0001	0.0007	

Appendix D (Continued)

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Subj	LSMEAN ReT LSMEAN	Number
S0	0.01571161	1
S1	0.01970261	2
S10	0.01902724	3
S11	0.01580000	4
S12	0.01873757	5
S13	0.01440995	6
S2	0.02066667	7
S3	0.01845979	8
S4	0.02531243	9
S5	0.02046667	10
S6	0.01456730	11
S7	0.01433333	12
S8	0.01355455	13
S9	0.01815476	14

Least Squares Means for effect Subj
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3	4	5	6	7
1		0.1657	0.4479	1.0000	0.5757	0.9995	0.0263
2	0.1657		1.0000	0.2526	1.0000	0.0133	1.0000
3	0.4479	1.0000		0.5685	1.0000	0.0620	0.9966
4	1.0000	0.2526	0.5685		0.6946	0.9994	0.0506
5	0.5757	1.0000	1.0000	0.6946		0.0985	0.9827

SAS Analysis – Phase 1

6	0.9995	0.0133	0.0620	0.9994	0.0985		0.0013
7	0.0263	1.0000	0.9966	0.0506	0.9827	0.0013	
8	0.7469	0.9998	1.0000	0.8356	1.0000	0.1847	0.9544
9	<.0001	0.0075	0.0012	<.0001	0.0004	<.0001	0.0792
10	0.0415	1.0000	0.9991	0.0757	0.9936	0.0022	1.0000
11	0.9999	0.0195	0.0859	0.9998	0.1327	1.0000	0.0020
12	0.9992	0.0135	0.0620	0.9991	0.0972	1.0000	0.0013
13	0.9457	0.0013	0.0083	0.9471	0.0145	1.0000	<.0001
14	0.8992	0.9984	1.0000	0.9412	1.0000	0.3456	0.9068

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Least Squares Means for effect Subj
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	8	9	10	11	12	13	14
1	0.7469	<.0001	0.0415	0.9999	0.9992	0.9457	0.8992
2	0.9998	0.0075	1.0000	0.0195	0.0135	0.0013	0.9984
3	1.0000	0.0012	0.9991	0.0859	0.0620	0.0083	1.0000
4	0.8356	<.0001	0.0757	0.9998	0.9991	0.9471	0.9412
5	1.0000	0.0004	0.9936	0.1327	0.0972	0.0145	1.0000
6	0.1847	<.0001	0.0022	1.0000	1.0000	1.0000	0.3456
7	0.9544	0.0792	1.0000	0.0020	0.0013	<.0001	0.9068
8		0.0002	0.9789	0.2375	0.1804	0.0342	1.0000
9	0.0002		0.0530	<.0001	<.0001	<.0001	0.0002
10	0.9789	0.0530		0.0034	0.0023	0.0002	0.9488
11	0.2375	<.0001	0.0034		1.0000	1.0000	0.4181
12	0.1804	<.0001	0.0023	1.0000		1.0000	0.3373
13	0.0342	<.0001	0.0002	1.0000	1.0000		0.0886
14	1.0000	0.0002	0.9488	0.4181	0.3373	0.0886	

SAS Analysis – Phase 1

Three-way ANOVA of ReT data set: Testing Interaction of ensemble x proto

The GLM Procedure

Dependent Variable: ReT   ReT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	27	0.00989843	0.00036661	25.04	<.0001
Error	192	0.00281053	0.00001464		
Corrected Total	219	0.01270896			

R-Square	Coeff Var	Root MSE	ReT Mean
0.778854	21.51080	0.003826	0.017786

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00475024	0.00118756	81.13	<.0001
Proto	2	0.00273468	0.00136734	93.41	<.0001
Ensemble*Proto	8	0.00022513	0.00002814	1.92	0.0587
Subj	13	0.00218838	0.00016834	11.50	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00446782	0.00111696	76.30	<.0001
Proto	2	0.00258380	0.00129190	88.26	<.0001
Ensemble*Proto	8	0.00027748	0.00003468	2.37	0.0187
Subj	13	0.00218838	0.00016834	11.50	<.0001

Appendix D (Continued)

SAS Analysis – Phase 1

```
              Analysis of ReT using the Mixed Model

                      The Mixed Procedure

                       Model Information

          Data Set                        VC.RET
            Dependent Variable             ReT
    Covariance Structure           Variance Components
             Estimation Method             REML
           Residual Variance Method      Profile
         Fixed Effects SE Method        Model-Based
         Degrees of Freedom Method      Containment


                   Class Level Information

             Class        Levels    Values

           Ensemble          5     A B C D E
            Proto            3      R2 R5 R7
            Subj            14      S0 S1 S10 S11 S12 S13 S2 S3 S4
                                     S5 S6 S7 S8 S9


                          Dimensions

          Covariance Parameters              2
          Columns in X                       9
          Columns in Z                      14
          Subjects                           1
          Max Obs Per Subject              220
          Observations Used                220
          Observations Not Used              0
          Total Observations               220
```

Appendix D (Continued)

SAS Analysis – Phase 1

Analysis of ReT using the Mixed Model

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
Subj	9.648E-6
Residual	0.000015

Fit Statistics

-2 Res Log Likelihood	-1697.9
AIC (smaller is better)	-1693.9
AICC (smaller is better)	-1693.9
BIC (smaller is better)	-1692.7

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Ensemble	4	200	73.65	<.0001
Proto	2	200	85.00	<.0001

SAS Analysis – Phase 1

Analysis of ReT using the Mixed Model

The Mixed Procedure

Least Squares Means

Effect	Ensemble	Proto	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha
Proto		R5	0.01664	0.000945	200	17.59	<.0001	0.05
Proto		R7	0.01418	0.000951	200	14.90	<.0001	0.05

Least Squares Means

Effect	Ensemble	Proto	Lower	Upper
Proto		R5	0.01477	0.01850
Proto		R7	0.01230	0.01605

Differences of Least Squares Means

Effect	Ensemble	Proto	Ensemble	Proto	Adjustment	Adj P	Alpha	Lower	Upper
Ensemble	A		B		Tukey-Kramer	0.9900	0.05	-0.00207	0.001277
Ensemble	A		C		Tukey-Kramer	0.2002	0.05	-0.00352	-0.00016
Ensemble	A		D		Tukey-Kramer	0.0002	0.05	-0.00532	-0.00200
Ensemble	A		E		Tukey-Kramer	<.0001	0.05	-0.01402	-0.01069
Ensemble	B		C		Tukey-Kramer	0.4309	0.05	-0.00311	0.000222

SAS Analysis – Phase 1

Analysis of $var1 using the Mixed Model

The Mixed Procedure

Differences of Least Squares Means

Effect	Ensemble	Proto	Ensemble	Proto	Estimate	Standard Error	DF	t Value	Pr > |t|
Ensemble	B		D		-0.00326	0.000831	200	-3.92	0.0001
Ensemble	B		E		-0.01195	0.000836	200	-14.30	<.0001
Ensemble	C		D		-0.00182	0.000836	200	-2.17	0.0310
Ensemble	C		E		-0.01051	0.000839	200	-12.52	<.0001
Ensemble	D		E		-0.00869	0.000827	200	-10.52	<.0001
Proto		R2		R5	0.005875	0.000649	200	9.06	<.0001
Proto		R2		R7	0.008333	0.000657	200	12.67	<.0001
Proto		R5		R7	0.002458	0.000649	200	3.79	0.0002

Differences of Least Squares Means

Effect	Ensemble	Proto	Ensemble	Proto	Adjustment	Adj P	Alpha	Lower	Upper
Ensemble	B		D		Tukey-Kramer	0.0011	0.05	-0.00490	-0.00162
Ensemble	B		E		Tukey-Kramer	<.0001	0.05	-0.01360	-0.01031
Ensemble	C		D		Tukey-Kramer	0.1943	0.05	-0.00347	-0.00017
Ensemble	C		E		Tukey-Kramer	<.0001	0.05	-0.01217	-0.00886
Ensemble	D		E		Tukey-Kramer	<.0001	0.05	-0.01032	-0.00706
Proto		R2		R5	Tukey-Kramer	<.0001	0.05	0.004596	0.007154
Proto		R2		R7	Tukey-Kramer	<.0001	0.05	0.007037	0.009630
Proto		R5		R7	Tukey-Kramer	0.0006	0.05	0.001179	0.003738

Appendix D (Continued)

SAS Analysis – Phase 1

```
              Three way ANOVA using Proc GLM for ReT Data without Ensemble E

                                    The GLM Procedure

                                 Class Level Information

                              Class          Levels    Values

                              Ensemble            4    A B C D

                              Proto               3    R2 R5 R7

         Subj                     14    S0 S1 S10 S11 S12 S13 S2 S3 S4 S5 S6 S7 S8 S9


                               Number of observations    175
```

Appendix D (Continued)

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data without Ensemble E

The GLM Procedure

Dependent Variable: ReT ReT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	0.00369821	0.00020546	24.04	<.0001
Error	156	0.00133330	0.00000855		
Corrected Total	174	0.00503151			

R-Square	Coeff Var	Root MSE	ReT Mean
0.735010	18.81614	0.002923	0.015537

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Ensemble	3	0.00042199	0.00014066	16.46	<.0001
Proto	2	0.00167469	0.00083735	97.97	<.0001
Subj	13	0.00160153	0.00012319	14.41	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ensemble	3	0.00038764	0.00012921	15.12	<.0001
Proto	2	0.00153307	0.00076653	89.69	<.0001
Subj	13	0.00160153	0.00012319	14.41	<.0001

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data without Ensemble E

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Ensemble	ReT LSMEAN	LSMEAN Number
A	0.01405075	1
B	0.01450732	2
C	0.01593123	3
D	0.01785464	4

Least Squares Means for effect Ensemble
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3	4
1		0.8884	0.0184	<.0001
2	0.8884		0.1109	<.0001
3	0.0184	0.1109		0.0126
4	<.0001	<.0001	0.0126	

Appendix D (Continued)

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data without Ensemble E

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Proto	LSMEAN ReT LSMEAN	Number
R2	0.01974149	1
R5	0.01431330	2
R7	0.01270317	3

Least Squares Means for effect Proto
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3
1		<.0001	<.0001
2	<.0001		0.0092
3	<.0001	0.0092	

Appendix D (Continued)

SAS Analysis – Phase 1

Three way ANOVA using Proc GLM for ReT Data without Ensemble E

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Subj	ReT LSMEAN	LSMEAN Number
S0	0.01386180	1
S1	0.01864754	2
S10	0.01741667	3
S11	0.01325000	4
S12	0.01573967	5
S13	0.01258333	6
S2	0.01700000	7
S3	0.01574064	8
S4	0.02341347	9
S5	0.01783333	10
S6	0.01342597	11
S7	0.01283333	12
S8	0.01100000	13
S9	0.01545805	14

Least Squares Means for effect Subj
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3	4	5	6	7
1		0.0023	0.1066	1.0000	0.9036	0.9974	0.2522
2	0.0023		0.9987	0.0007	0.3645	<.0001	0.9798
3	0.1066	0.9987		0.0389	0.9731	0.0060	1.0000
4	1.0000	0.0007	0.0389		0.6569	1.0000	0.1047
5	0.9036	0.3645	0.9731	0.6569		0.2661	0.9981

SAS Analysis – Phase 1

6	0.9974	<.0001	0.0060	1.0000	0.2661		0.0200
7	0.2522	0.9798	1.0000	0.1047	0.9981	0.0200	
8	0.9165	0.4003	0.9773	0.6858	1.0000	0.2956	0.9984
9	<.0001	0.0057	0.0001	<.0001	<.0001	<.0001	<.0001
10	0.0376	1.0000	1.0000	0.0126	0.8645	0.0016	1.0000
11	1.0000	0.0009	0.0499	1.0000	0.7337	1.0000	0.1316
12	0.9997	0.0002	0.0126	1.0000	0.3985	1.0000	0.0389
13	0.3989	<.0001	<.0001	0.8314	0.0047	0.9879	0.0001
14	0.9840	0.3128	0.9427	0.8693	1.0000	0.5182	0.9923

SAS Analysis – Phase 1

```
Three way ANOVA using Proc GLM for ReT Data without Ensemble E

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Least Squares Means for effect Subj
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT
```

i/j	8	9	10	11	12	13	14
1	0.9165	<.0001	0.0376	1.0000	0.9997	0.3989	0.9840
2	0.4003	0.0057	1.0000	0.0009	0.0002	<.0001	0.3128
3	0.9773	0.0001	1.0000	0.0499	0.0126	<.0001	0.9427
4	0.6858	<.0001	0.0126	1.0000	1.0000	0.8314	0.8693
5	1.0000	<.0001	0.8645	0.7337	0.3985	0.0047	1.0000
6	0.2956	<.0001	0.0016	1.0000	1.0000	0.9879	0.5182
7	0.9984	<.0001	1.0000	0.1316	0.0389	0.0001	0.9923
8		<.0001	0.8808	0.7592	0.4316	0.0063	1.0000
9	<.0001		0.0005	<.0001	<.0001	<.0001	<.0001
10	0.8808	0.0005		0.0163	0.0036	<.0001	0.7982
11	0.7592	<.0001	0.0163		1.0000	0.7191	0.9150
12	0.4316	<.0001	0.0036	1.0000		0.9588	0.6660
13	0.0063	<.0001	<.0001	0.7191	0.9588		0.0236
14	1.0000	<.0001	0.7982	0.9150	0.6660	0.0236	

SAS Analysis – Phase 1

Three-way ANOVA of ReT data set: Testing Interaction of ensemble x proto without Ensemble E

The GLM Procedure

Dependent Variable: ReT   ReT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	24	0.00371890	0.00015495	17.71	<.0001
Error	150	0.00131261	0.00000875		
Corrected Total	174	0.00503151			

R-Square	Coeff Var	Root MSE	ReT Mean
0.739122	19.03931	0.002958	0.015537

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Ensemble	3	0.00042199	0.00014066	16.07	<.0001
Proto	2	0.00167469	0.00083735	95.69	<.0001
Ensemble*Proto	6	0.00001444	0.00000241	0.28	0.9479
Subj	13	0.00160777	0.00012367	14.13	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ensemble	3	0.00038033	0.00012678	14.49	<.0001
Proto	2	0.00153345	0.00076673	87.62	<.0001
Ensemble*Proto	6	0.00002069	0.00000345	0.39	0.8820
Subj	13	0.00160777	0.00012367	14.13	<.0001

APPENDIX E

SAS CODE AND ANALYSIS – PHASE 2

Appendix E

SAS Code – Phase 2

```
options nodate nonumber;
libname Vc 'F:\USF\NIOSH Studies\evap res Yr2\';

* SAS Code for Analyzing Re,T for Phase 2;

%macro mean1 (var1, var2, var3, var4);
Proc Means data=Vc.ret n mean var std stddev;
      title "SAS Analysis of Pase 2 Data";
      Class &var2 &var3 &var4;
      var &var1;
Run;
%mend;
%mean1 (ReT, ensemble);
%mean1 (ReT, ensemble, M);
%mean1 (ReT, M);

%macro anov1 (var1, var2, var3, var4);
Proc glm data=vc.ret;
      title "Three way ANOVA using Proc GLM for &var1 Data";
      Class &var2 &var3 &var4;
      Model &var1 = &var2 &var3 &var4;
      lsmeans &var2 &var3 &var4 /pdiff adjust=Tukey alpha=0.05;
      run;
%mend;
%anov1 (ReT, ensemble, M, subj);

%macro anov2 (var1, var2, var3, var4);
Proc glm data=vc.ret;
      title "Three-way ANOVA of &var1 data set: Testing Interaction of
&var2 x &var3";
      Class &var2 &var3 &var4;
      Model &var1 = &var2 | &var3 &var4;
      lsmeans &var2 | &var3 /pdiff adjust=Tukey alpha=0.05;
      run;
%mend;
%anov2 (ReT, ensemble, M, subj);

%macro mixed1 (var1, var2, var3, var4);
Proc mixed data=vc.ret;
      title "Analysis of $var1 using the Mixed Model";
      Class &var2 &var3 &var4;
      Model &var1 = &var2 &var3;
      Random &var4;
      LSmeans &var2 &var3 /adjust=tukey alpha=.05;
      run;
%mend;
%mixed1 (ReT, ensemble, M, subj);
```

SAS Analysis – Phase 2

SAS Analysis of Phase 2 Data

The MEANS Procedure

Analysis Variable : ReT ReT

Ensemble	Obs	N	N Mean	Variance	Std Dev
A	44	44	0.0114318	5.5533827E-6	0.0023566
B	42	42	0.0121667	8.0934959E-6	0.0028449
C	46	46	0.0126304	9.2603865E-6	0.0030431
D	45	45	0.0152889	0.000016846	0.0041044
E	48	48	0.0235833	0.000031525	0.0056147

Appendix E (Continued)

SAS Analysis – Phase 2

SAS Analysis of Phase 2 Data

The MEANS Procedure

Analysis Variable : ReT ReT

Ensemble	M	Obs	N	Mean	Variance	Std Dev
A	M1	14	14	0.0110714	4.0714286E-6	0.0020178
	M2	15	15	0.0125333	8.9809524E-6	0.0029968
	M3	15	15	0.0106667	2.2380952E-6	0.0014960
B	M1	14	14	0.0135714	6.4175824E-6	0.0025333
	M2	14	14	0.0117857	3.8736264E-6	0.0019682
	M3	14	14	0.0111429	0.000011824	0.0034386
C	M1	16	16	0.0149375	0.000013663	0.0036963
	M2	15	15	0.0119333	3.352381E-6	0.0018310
	M3	15	15	0.0108667	1.8380952E-6	0.0013558
D	M1	15	15	0.0183333	0.000024238	0.0049232
	M2	15	15	0.0152000	4.6E-6	0.0021448
	M3	15	15	0.0123333	4.8095238E-6	0.0021931
E	M1	16	16	0.0282500	0.000026200	0.0051186
	M2	15	15	0.0239333	0.000013781	0.0037123
	M3	17	17	0.0188824	0.000010610	0.0032573

Appendix E (Continued)

SAS Analysis – Phase 2

SAS Analysis of Phase 2 Data

The MEANS Procedure

Analysis Variable : ReT ReT

M	Obs	N	N Mean	Variance	Std Dev
M1	75	75	0.0174800	0.000051794	0.0071968
M2	74	74	0.0151216	0.000028136	0.0053043
M3	76	76	0.0129605	0.000016545	0.0040676

Appendix E (Continued)

SAS Analysis – Phase 2

```
Three way ANOVA using Proc GLM for ReT Data

           The GLM Procedure

        Class Level Information

   Class          Levels    Values

  Ensemble           5     A B C D E

  M                  3     M1 M2 M3

  Subj              15     1 2 3 4 5 6 7 8 9 10 11 12 13 15 16


   Number of observations     225
```

Appendix E (Continued)

SAS Analysis – Phase 2

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure

Dependent Variable: ReT ReT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	0.00603568	0.00030178	33.04	<.0001
Error	204	0.00186321	0.00000913		
Corrected Total	224	0.00789889			

R-Square	Coeff Var	Root MSE	ReT Mean
0.764117	19.91167	0.003022	0.015178

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00468863	0.00117216	128.34	<.0001
M	2	0.00080444	0.00040222	44.04	<.0001
Subj	14	0.00054261	0.00003876	4.24	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00465386	0.00116347	127.39	<.0001
M	2	0.00080189	0.00040094	43.90	<.0001
Subj	14	0.00054261	0.00003876	4.24	<.0001

Appendix E (Continued)

SAS Analysis – Phase 2

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Ensemble	LSMEAN ReT LSMEAN	Number
A	0.01151359	1
B	0.01204646	2
C	0.01261354	3
D	0.01528889	4
E	0.02358058	5

Least Squares Means for effect Ensemble
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3	4	5
1		0.9257	0.4212	<.0001	<.0001
2	0.9257		0.9050	<.0001	<.0001
3	0.4212	0.9050		0.0004	<.0001
4	<.0001	<.0001	0.0004		<.0001
5	<.0001	<.0001	<.0001	<.0001	

Appendix E (Continued)

SAS Analysis – Phase 2

```
Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

                 LSMEAN
M          ReT LSMEAN      Number

M1         0.01728715           1
M2         0.01506492           2
M3         0.01267376           3


Least Squares Means for effect M
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j             1             2             3

  1                     <.0001        <.0001
  2        <.0001                     <.0001
  3        <.0001       <.0001
```

SAS Analysis – Phase 2

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Subj	ReT LSMEAN	LSMEAN Number
1	0.01540000	1
2	0.01415582	2
3	0.01540000	3
4	0.01393333	4
5	0.01553333	5
6	0.01466667	6
7	0.01350728	7
8	0.01888148	8
9	0.01166546	9
10	0.01493333	10
11	0.01686667	11
12	0.01632821	12
13	0.01493333	13
15	0.01440000	14
16	0.01452426	15

Least Squares Means for effect Subj
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	1	2	3	4	5	6	7	8
1		0.9992	1.0000	0.9918	1.0000	1.0000	0.9173	0.1104
2	0.9992		0.9992	1.0000	0.9977	1.0000	1.0000	0.0067
3	1.0000	0.9992		0.9918	1.0000	1.0000	0.9173	0.1104
4	0.9918	1.0000	0.9918		0.9815	1.0000	1.0000	0.0012

SAS Analysis – Phase 2

5	1.0000	0.9977	1.0000	0.9815		1.0000	0.8676	0.1502
6	1.0000	1.0000	1.0000	1.0000	1.0000		0.9992	0.0144
7	0.9173	1.0000	0.9173	1.0000	0.8676	0.9992		0.0002
8	0.1104	0.0067	0.1104	0.0012	0.1502	0.0144	0.0002	
9	0.0691	0.7382	0.0691	0.7852	0.0487	0.3305	0.9414	<.0001
10	1.0000	1.0000	1.0000	0.9999	1.0000	1.0000	0.9927	0.0321
11	0.9918	0.5839	0.9918	0.3385	0.9968	0.7998	0.1295	0.8853
12	0.9999	0.8667	0.9999	0.6662	1.0000	0.9712	0.3555	0.5638
13	1.0000	1.0000	1.0000	0.9999	1.0000	1.0000	0.9927	0.0321
14	0.9999	1.0000	0.9999	1.0000	0.9995	1.0000	1.0000	0.0060
15	1.0000	1.0000	1.0000	1.0000	0.9998	1.0000	0.9997	0.0060

Appendix E (Continued)

SAS Analysis – Phase 2

Three way ANOVA using Proc GLM for ReT Data

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Least Squares Means for effect Subj
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: ReT

i/j	9	10	11	12	13	14	15
1	0.0691	1.0000	0.9918	0.9999	1.0000	0.9999	1.0000
2	0.7382	1.0000	0.5839	0.8667	1.0000	1.0000	1.0000
3	0.0691	1.0000	0.9918	0.9999	1.0000	0.9999	1.0000
4	0.7852	0.9999	0.3385	0.6662	0.9999	1.0000	1.0000
5	0.0487	1.0000	0.9968	1.0000	1.0000	0.9995	0.9998
6	0.3305	1.0000	0.7998	0.9712	1.0000	1.0000	1.0000
7	0.9414	0.9927	0.1295	0.3555	0.9927	1.0000	0.9997
8	<.0001	0.0321	0.8853	0.5638	0.0321	0.0060	0.0060
9		0.2016	0.0006	0.0036	0.2016	0.4931	0.3648
10	0.2016		0.9138	0.9943	1.0000	1.0000	1.0000
11	0.0006	0.9138		1.0000	0.9138	0.6392	0.6747
12	0.0036	0.9943	1.0000		0.9943	0.9075	0.9274
13	0.2016	1.0000	0.9138	0.9943		1.0000	1.0000
14	0.4931	1.0000	0.6392	0.9075	1.0000		1.0000
15	0.3648	1.0000	0.6747	0.9274	1.0000	1.0000	

Appendix E (Continued)

SAS Analysis – Phase 2

Three-way ANOVA of ReT data set: Testing Interaction of ensemble x M

The GLM Procedure

Dependent Variable: ReT ReT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	28	0.00642128	0.00022933	30.42	<.0001
Error	196	0.00147761	0.00000754		
Corrected Total	224	0.00789889			

R-Square	Coeff Var	Root MSE	ReT Mean
0.812934	18.09023	0.002746	0.015178

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00468863	0.00117216	155.48	<.0001
M	2	0.00080444	0.00040222	53.35	<.0001
Ensemble*M	8	0.00040395	0.00005049	6.70	<.0001
Subj	14	0.00052425	0.00003745	4.97	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ensemble	4	0.00470708	0.00117677	156.09	<.0001
M	2	0.00074264	0.00037132	49.25	<.0001
Ensemble*M	8	0.00038560	0.00004820	6.39	<.0001
Subj	14	0.00052425	0.00003745	4.97	<.0001

SAS Analysis – Phase 2

```
                 Analysis of $var1 using the Mixed Model

                          The Mixed Procedure

                           Model Information

              Data Set                         VC.RET
                Dependent Variable              ReT
      Covariance Structure              Variance Components
                Estimation Method               REML
              Residual Variance Method        Profile
            Fixed Effects SE Method         Model-Based
            Degrees of Freedom Method       Containment


                       Class Level Information

                   Class         Levels     Values

                 Ensemble          5     A B C D E
               M                   3    M1 M2 M3
               Subj               15    1 2 3 4 5 6 7 8 9 10 11 12 13
                                        15 16


                               Dimensions

              Covariance Parameters                2
              Columns in X                         9
              Columns in Z                        15
              Subjects                             1
              Max Obs Per Subject                225
              Observations Used                  225
              Observations Not Used                0
              Total Observations                 225


                           Iteration History
```

SAS Analysis – Phase 2

Analysis of ReT using the Mixed Model

The Mixed Procedure

Covariance Parameter Estimates

Cov Parm	Estimate
Subj	2.001E-6
Residual	9.135E-6

Fit Statistics

-2 Res Log Likelihood	-1864.0
AIC (smaller is better)	-1860.0
AICC (smaller is better)	-1859.9
BIC (smaller is better)	-1858.6

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Ensemble	4	204	127.77	<.0001
M	2	204	43.94	<.0001

Appendix E (Continued)

SAS Analysis – Phase 2

Effect	Ensemble	M	Ensemble	M	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment
Ensemble	A		B		-0.00057	0.000653	204	-0.87	0.3837	Tukey-Kramer
Ensemble	A		C		-0.00110	0.000638	204	-1.72	0.0862	Tukey-Kramer
Ensemble	A		D		-0.00378	0.000641	204	-5.90	<.0001	Tukey-Kramer
Ensemble	A		E		-0.01209	0.000633	204	-19.10	<.0001	Tukey-Kramer
Ensemble	B		C		-0.00053	0.000646	204	-0.82	0.4138	Tukey-Kramer
Ensemble	B		D		-0.00321	0.000650	204	-4.94	<.0001	Tukey-Kramer
Ensemble	B		E		-0.01152	0.000640	204	-18.00	<.0001	Tukey-Kramer
Ensemble	C		D		-0.00268	0.000634	204	-4.23	<.0001	Tukey-Kramer
Ensemble	C		E		-0.01099	0.000625	204	-17.57	<.0001	Tukey-Kramer
Ensemble	D		E		-0.00830	0.000629	204	-13.21	<.0001	Tukey-Kramer
M		M1		M2	0.002225	0.000498	204	4.47	<.0001	Tukey-Kramer
M		M1		M3	0.004615	0.000492	204	9.37	<.0001	Tukey-Kramer
M		M2		M3	0.002390	0.000495	204	4.83	<.0001	Tukey-Kramer

Differences of Least Squares Means

Effect	Ensemble	M	Ensemble	M	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
Ensemble	A		B		0.9065	0.05	-0.00186	0.000718	.	.
Ensemble	A		C		0.4215	0.05	-0.00236	0.000158	.	.
Ensemble	A		D		<.0001	0.05	-0.00505	-0.00252	.	.
Ensemble	A		E		<.0001	0.05	-0.01334	-0.01084	.	.
Ensemble	B		C		0.9246	0.05	-0.00180	0.000745	.	.
Ensemble	B		D		<.0001	0.05	-0.00449	-0.00193	.	.
Ensemble	B		E		<.0001	0.05	-0.01278	-0.01025	.	.
Ensemble	C		D		0.0003	0.05	-0.00393	-0.00143	.	.
Ensemble	C		E		<.0001	0.05	-0.01222	-0.00975	.	.
Ensemble	D		E		<.0001	0.05	-0.00954	-0.00707	.	.
M		M1		M2	<.0001	0.05	0.001244	0.003206	.	.
M		M1		M3	<.0001	0.05	0.003644	0.005586	.	.
M		M2		M3	<.0001	0.05	0.001415	0.003365	.	.

APPENDIX F

JMP IN DATA ANALYSIS – PROTOCOLS

Appendix F

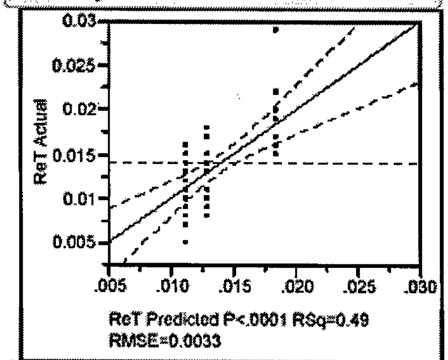
$R_{e,T}$ Response to Protocol (Environment) by Ensemble

Ensemble=A

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.485641
RSquare Adj	0.459263
Root Mean Square Error	0.00326
Mean of Response	0.013952
Observations (or Sum Wgts)	42

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00039138	0.000196	18.4112
Error	39	0.00041452	0.000011	Prob > F
C. Total	41	0.00080590		<.0001

Parameter Estimates

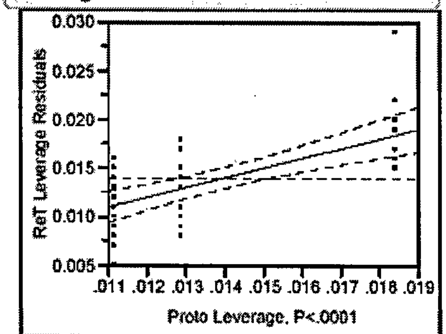
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.014125	0.000504	28.03	<.0001
Proto[R2]	0.0042596	0.000726	5.87	<.0001
Proto[R5]	-0.001268	0.000712	-1.78	0.0828

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Proto	2	2	0.00039138	18.4112	<.0001

Proto

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
R2	0.01838462	0.00090421	0.018385
R5	0.01285714	0.00087132	0.012857
R7	0.01113333	0.00084178	0.011133

Appendix F (Continued)

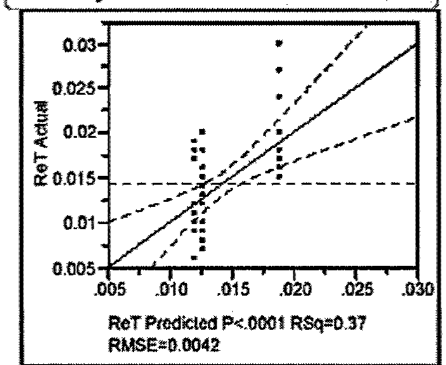
$R_{e,T}$ Response to Protocol (Environment) by Ensemble

Ensemble=B

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.365212
RSquare Adj	0.334247
Root Mean Square Error	0.004164
Mean of Response	0.014341
Observations (or Sum Wgts)	44

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00040900	0.000204	11.7942
Error	41	0.00071089	0.000017	Prob > F
C. Total	43	0.00111989		<.0001

Parameter Estimates

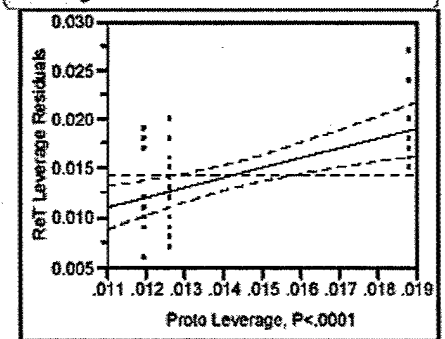
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0144397	0.000628	22.99	<.0001
Proto[R2]	0.004346	0.000899	4.84	<.0001
Proto[R5]	-0.00184	0.000883	-2.08	0.0435

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Proto	2	2	0.00040900	11.7942	<.0001

Proto

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
R2	0.01878571	0.00111287	0.018786
R5	0.01260000	0.00107514	0.012600
R7	0.01193333	0.00107514	0.011933

Appendix F (Continued)

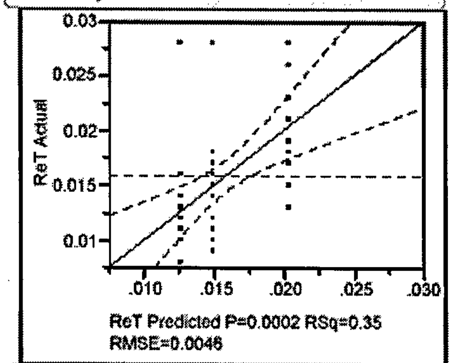
$R_{e,T}$ Response to Protocol (Environment) by Ensemble

Ensemble=C

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.348182
RSquare Adj	0.315591
Root Mean Square Error	0.004611
Mean of Response	0.015814
Observations (or Sum Wgts)	43

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00045421	0.000227	10.6834
Error	40	0.00085030	0.000021	Prob > F
C. Total	42	0.00130451		0.0002

Parameter Estimates

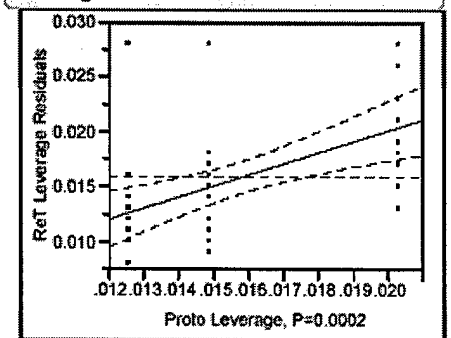
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0158921	0.000703	22.59	<.0001
Proto[R2]	0.0043937	0.001001	4.39	<.0001
Proto[R5]	-0.001035	0.001001	-1.03	0.3072

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Proto	2	2	0.00045421	10.6834	0.0002

Proto

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
R2	0.02028571	0.00123223	0.020286
R5	0.01485714	0.00123223	0.014857
R7	0.01253333	0.00119045	0.012533

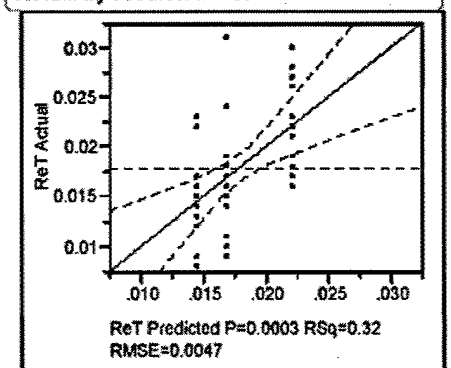
$R_{e,T}$ Response to Protocol (Environment) by Ensemble

Ensemble=D

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.315072
RSquare Adj	0.283215
Root Mean Square Error	0.004687
Mean of Response	0.01787
Observations (or Sum Wgts)	46

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00043455	0.000217	9.8902
Error	43	0.00094466	0.000022	Prob > F
C. Total	45	0.00137922		0.0003

Parameter Estimates

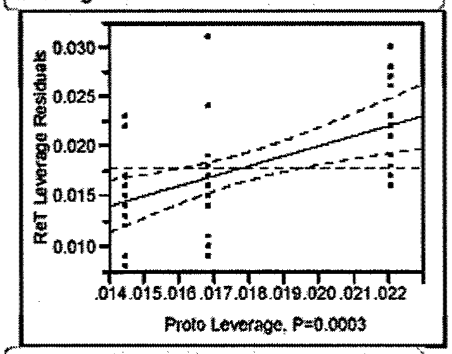
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0177872	0.000697	25.51	<.0001
Proto[R2]	0.0042795	0.000987	4.34	<.0001
Proto[R5]	-0.000954	0.000945	-1.01	0.3184

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Proto	2	2	0.00043455	9.8902	0.0003

Proto

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
R2	0.02206667	0.00121020	0.022067
R5	0.01683333	0.00110476	0.016833
R7	0.01446154	0.00129997	0.014462

Appendix F (Continued)

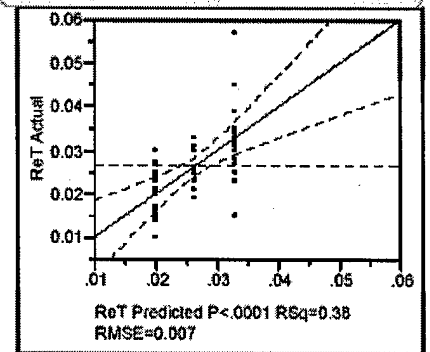
$R_{e,T}$ Response to Protocol (Environment) by Ensemble

Ensemble=E

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.379396
RSquare Adj	0.349843
Root Mean Square Error	0.007035
Mean of Response	0.026533
Observations (or Sum Wgts)	45

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00127067	0.000635	12.8380
Error	42	0.00207853	0.000049	Prob > F
C. Total	44	0.00334920		<.0001

Parameter Estimates

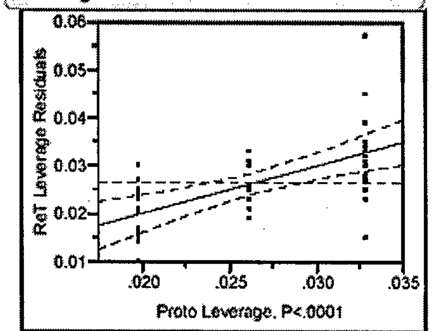
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0262438	0.00105	24.99	<.0001
Proto[R2]	0.0065687	0.001461	4.50	<.0001
Proto[R5]	-0.000111	0.001484	-0.07	0.9410

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Proto	2	2	0.00127067	12.8380	<.0001

Proto

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
R2	0.03281250	0.00175871	0.032812
R5	0.02613333	0.00181638	0.026133
R7	0.01978571	0.00188014	0.019786

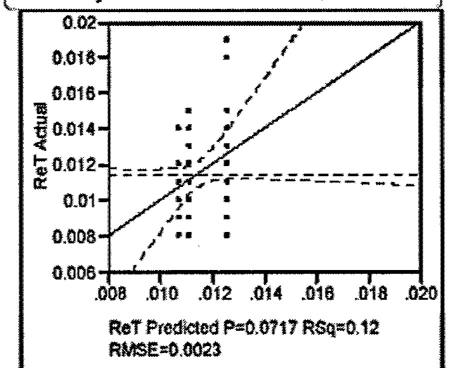
$R_{e,T}$ Response to Protocol (Metabolic Demand) by Ensemble

Ensemble=A

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.120606
RSquare Adj	0.077709
Root Mean Square Error	0.002263
Mean of Response	0.011432
Observations (or Sum Wgts)	44

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00002880	0.000014	2.8115
Error	41	0.00021000	0.000005	Prob > F
C. Total	43	0.00023880		0.0717

Parameter Estimates

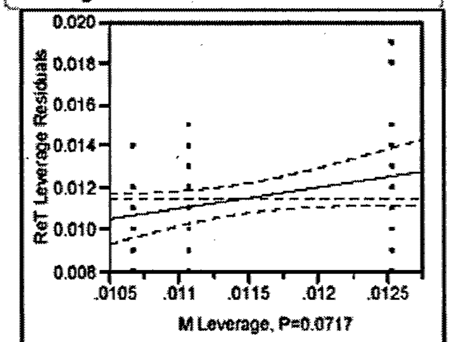
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0114238	0.000341	33.47	<.0001
M[M1]	-0.000352	0.000488	-0.72	0.4746
M[M2]	0.0011095	0.00048	2.31	0.0259

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
M	2	2	0.00002880	2.8115	0.0717

M

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M1	0.01107143	0.00060485	0.011071
M2	0.01253333	0.00058434	0.012533
M3	0.01066667	0.00058434	0.010667

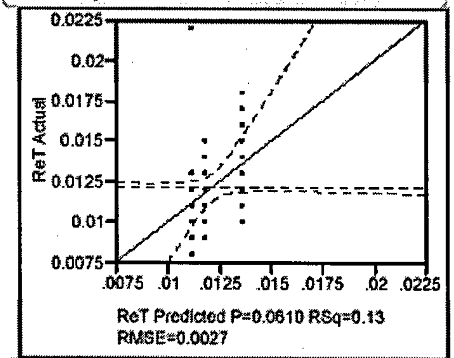
$R_{e,T}$ Response to Protocol (Metabolic Demand) by Ensemble

Ensemble=B

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.133601
RSquare Adj	0.08917
Root Mean Square Error	0.002715
Mean of Response	0.012167
Observations (or Sum Wgts)	42

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00004433	0.000022	3.0070
Error	39	0.00028750	0.000007	Prob > F
C. Total	41	0.00033183		0.0610

Parameter Estimates

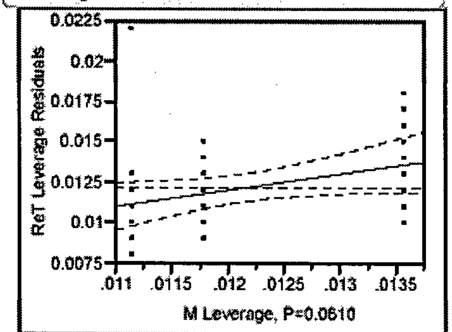
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0121667	0.000419	29.04	<.0001
M[M1]	0.0014048	0.000592	2.37	0.0228
M[M2]	-0.000381	0.000592	-0.64	0.5240

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
M	2	2	0.00004433	3.0070	0.0610

M

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M1	0.01357143	0.00072564	0.013571
M2	0.01178571	0.00072564	0.011786
M3	0.01114286	0.00072564	0.011143

Appendix F (Continued)

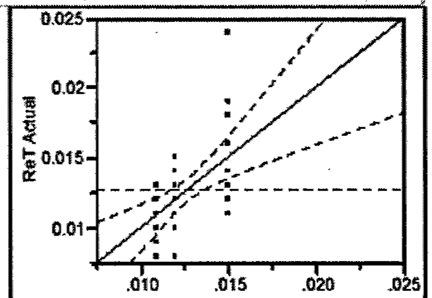
$R_{e,T}$ Response to Protocol (Metabolic Demand) by Ensemble

Ensemble=C

Response ReT

Whole Model

Actual by Predicted Plot



ReT Predicted P=0.0002 RSq=0.33
RMSE=0.0025

Summary of Fit

RSquare	0.333831
RSquare Adj	0.302846
Root Mean Square Error	0.002541
Mean of Response	0.01263
Observations (or Sum Wgts)	46

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00013911	0.000070	10.7741
Error	43	0.00027760	0.000006	Prob > F
C. Total	45	0.00041672		0.0002

Parameter Estimates

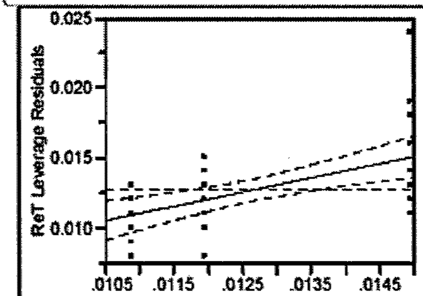
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0125792	0.000375	33.56	<.0001
M[M1]	0.0023583	0.000524	4.50	<.0001
M[M2]	-0.000646	0.000533	-1.21	0.2321

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
M	2	2	0.00013911	10.7741	0.0002

M

Leverage Plot



M Leverage, P=0.0002

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M1	0.01493750	0.00063521	0.014938
M2	0.01193333	0.00065604	0.011933
M3	0.01086667	0.00065604	0.010867

Appendix F (Continued)

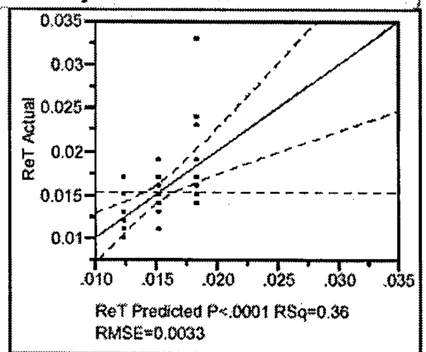
$R_{e,T}$ Response to Protocol (Metabolic Demand) by Ensemble

Ensemble=D

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.364492
RSquare Adj	0.33423
Root Mean Square Error	0.003349
Mean of Response	0.015289
Observations (or Sum Wgts)	45

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00027018	0.000135	12.0444
Error	42	0.00047107	0.000011	Prob > F
C. Total	44	0.00074124		<.0001

Parameter Estimates

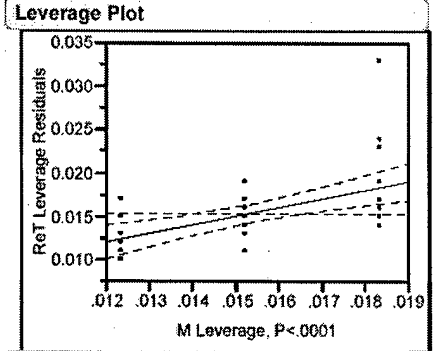
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0152889	0.000499	30.62	<.0001
M[M1]	0.0030444	0.000706	4.31	<.0001
M[M2]	-0.000089	0.000706	-0.13	0.9004

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
M	2	2	0.00027018	12.0444	<.0001

M

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M1	0.01833333	0.00086471	0.018333
M2	0.01520000	0.00086471	0.015200
M3	0.01233333	0.00086471	0.012333

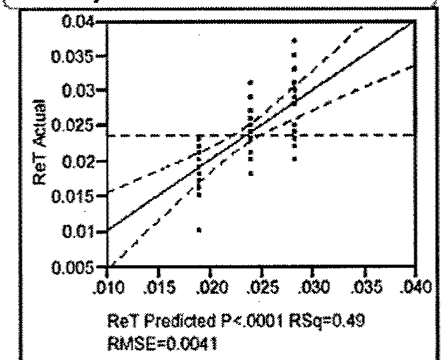
$R_{e,T}$ Response to Protocol (Metabolic Demand) by Ensemble

Ensemble=E

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.489968
RSquare Adj	0.467299
Root Mean Square Error	0.004098
Mean of Response	0.023583
Observations (or Sum Wgts)	48

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.00072597	0.000363	21.6148
Error	45	0.00075570	0.000017	Prob > F
C. Total	47	0.00148167		<.0001

Parameter Estimates

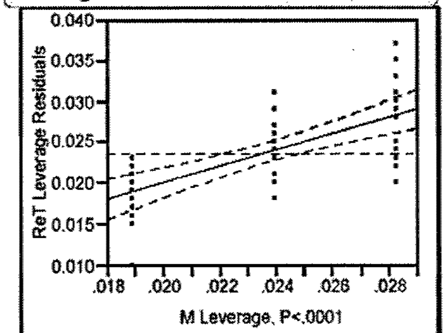
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0236886	0.000592	40.00	<.0001
M[M1]	0.0045614	0.000837	5.45	<.0001
M[M2]	0.0002448	0.000851	0.29	0.7749

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
M	2	2	0.00072597	21.6148	<.0001

M

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
M1	0.02825000	0.00102449	0.028250
M2	0.02393333	0.00105809	0.023933
M3	0.01888235	0.00099390	0.018882

APPENDIX G

JMP IN DATA ANALYSIS – M2R5

Appendix G

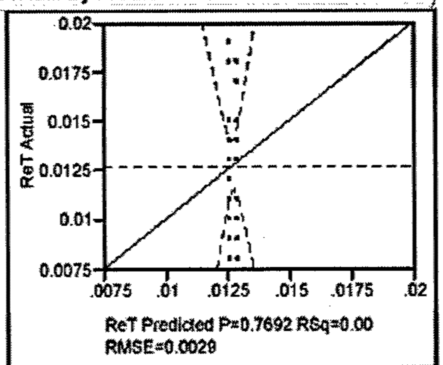
$R_{e,T}$ Response to Ensemble by Phase (M2R5 Dataset)

Ensemble=A

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.003242
RSquare Adj	-0.03368
Root Mean Square Error	0.00294
Mean of Response	0.01269
Observations (or Sum Wgts)	29

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00000076	7.5928e-7	0.0878
Error	27	0.00023345	0.0000086	Prob > F
C. Total	28	0.00023421		0.7692

Parameter Estimates

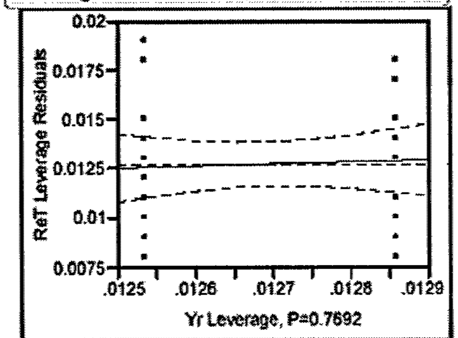
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0126952	0.000546	23.24	<.0001
Yr[Y1]	0.0001619	0.000546	0.30	0.7692

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Yr	1	1	7.59278e-7	0.0878	0.7692

Yr

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Y1	0.01285714	0.00078567	0.012857
Y2	0.01253333	0.00075922	0.012533

Appendix G (Continued)

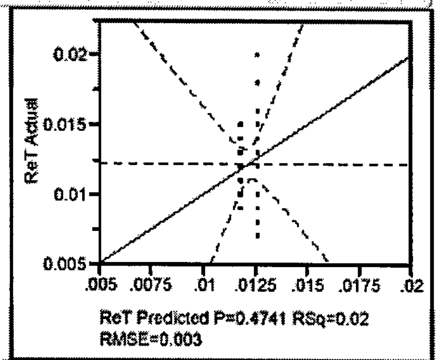
$R_{e,T}$ Response to Ensemble by Phase (M2R5 Dataset)

Ensemble=B

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.019148
RSquare Adj	-0.01718
Root Mean Square Error	0.003018
Mean of Response	0.012207
Observations (or Sum Wgts)	29

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00000480	0.0000048	0.5271
Error	27	0.00024596	0.0000091	Prob > F
C. Total	28	0.00025076		0.4741

Parameter Estimates

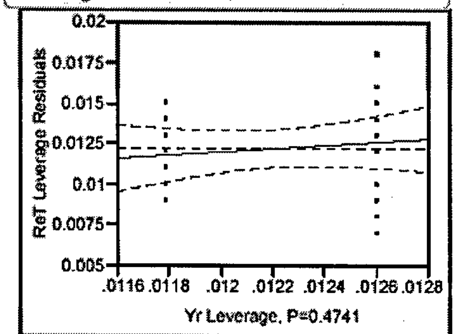
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0121929	0.000561	21.74	<.0001
Yr[Y1]	0.0004071	0.000561	0.73	0.4741

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Yr	1	1	0.0000048	0.5271	0.4741

Yr

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Y1	0.01260000	0.00077930	0.012600
Y2	0.01178571	0.00080665	0.011786

Appendix G (Continued)

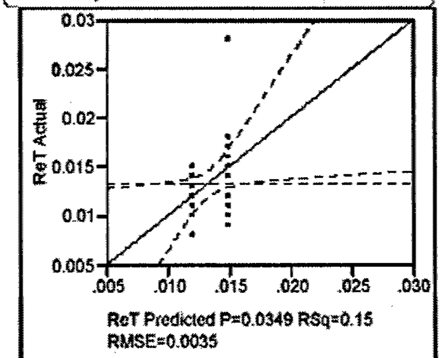
$R_{e,T}$ Response to Ensemble by Phase (M2R5 Dataset)

Ensemble=C

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.154547
RSquare Adj	0.123234
Root Mean Square Error	0.003542
Mean of Response	0.013345
Observations (or Sum Wgts)	29

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00006190	0.000062	4.9355
Error	27	0.00033865	0.000013	Prob > F
C. Total	28	0.00040055		0.0349

Parameter Estimates

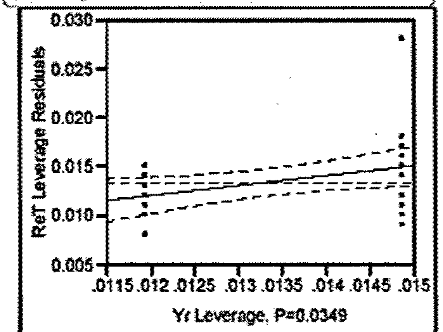
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0133952	0.000658	20.36	<.0001
Yr[Y1]	0.0014619	0.000658	2.22	0.0349

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Yr	1	1	0.00006190	4.9355	0.0349

Yr

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Y1	0.01485714	0.00094652	0.014857
Y2	0.01193333	0.00091442	0.011933

Appendix G (Continued)

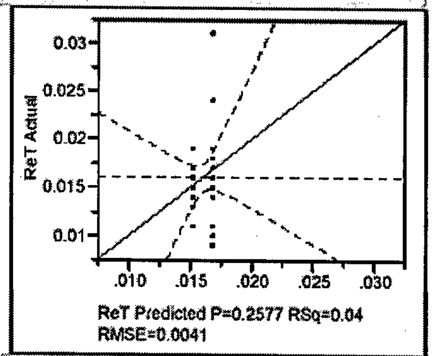
$R_{e,T}$ Response to Ensemble by Phase (M2R5 Dataset)

Ensemble=D

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.041127
RSquare Adj	0.010196
Root Mean Square Error	0.004052
Mean of Response	0.016091
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00002183	0.000022	1.3296
Error	31	0.00050890	0.000016	Prob > F
C. Total	32	0.00053073		0.2577

Parameter Estimates

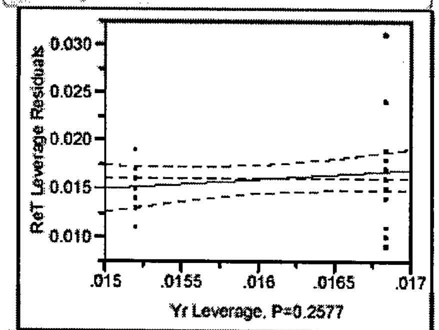
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0160167	0.000708	22.61	<.0001
Yr[Y1]	0.0008167	0.000708	1.15	0.2577

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Yr	1	1	0.00002183	1.3296	0.2577

Yr

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Y1	0.01683333	0.00095499	0.016833
Y2	0.01520000	0.00104614	0.015200

Appendix G (Continued)

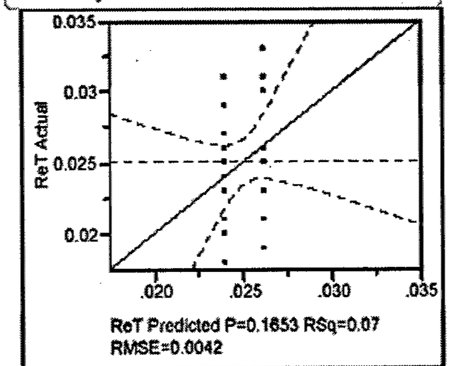
$R_{e,T}$ Response to Ensemble by Phase (M2R5 Dataset)

Ensemble=E

Response ReT

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.067602
RSquare Adj	0.034302
Root Mean Square Error	0.004229
Mean of Response	0.025033
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00003630	0.000036	2.0301
Error	28	0.00050067	0.000018	Prob > F
C. Total	29	0.00053697		0.1653

Parameter Estimates

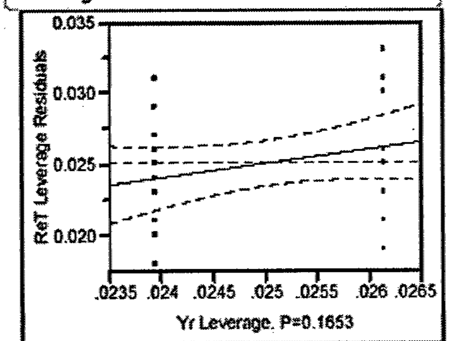
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0250333	0.000772	32.43	<.0001
Yr[Y1]	0.0011	0.000772	1.42	0.1653

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Yr	1	1	0.00003630	2.0301	0.1653

Yr

Leverage Plot



Least Squares Means Table

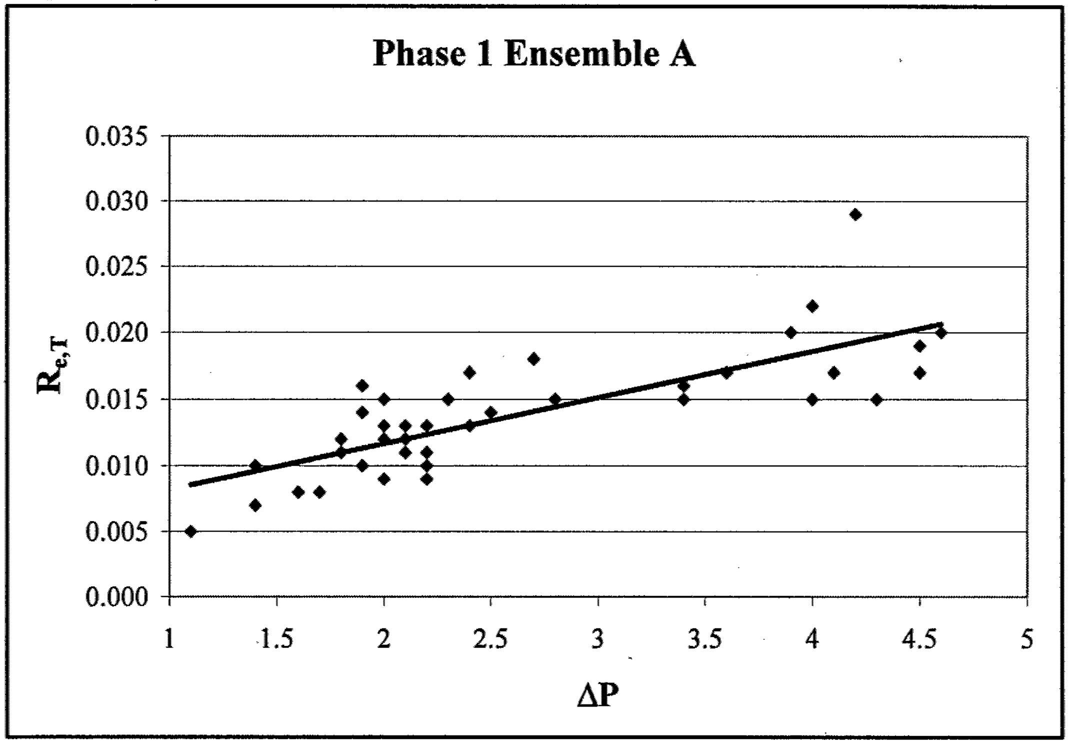
Level	Least Sq Mean	Std Error	Mean
Y1	0.02613333	0.00109182	0.026133
Y2	0.02393333	0.00109182	0.023933

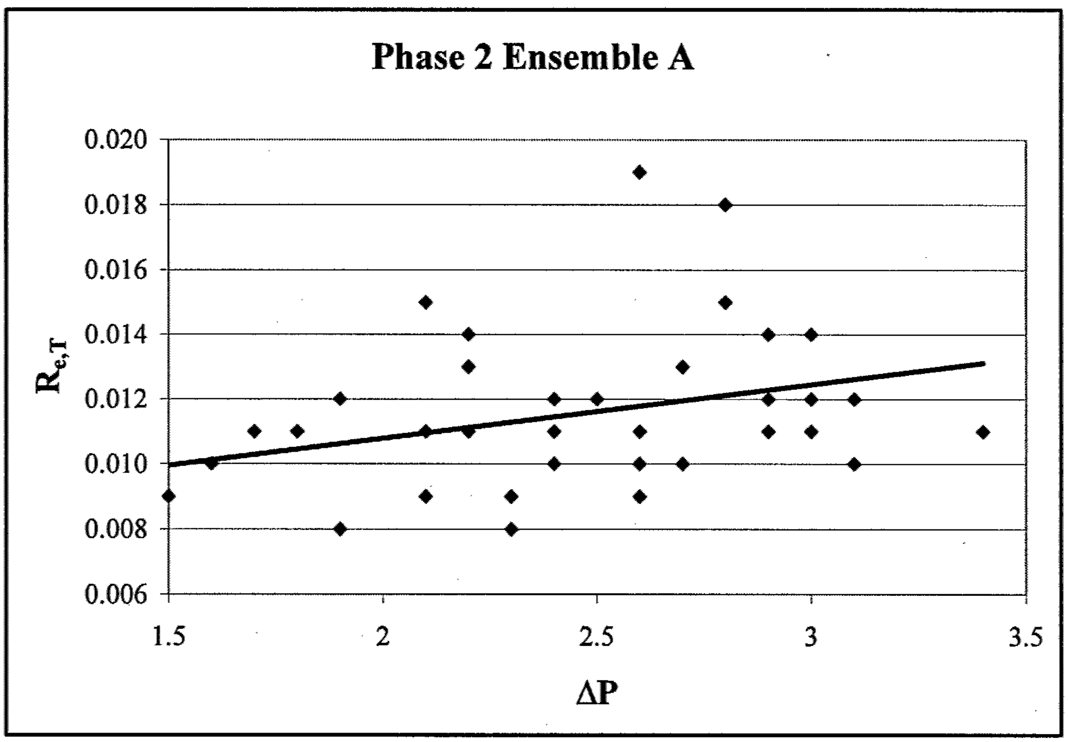
APPENDIX H

GRAPHS OF $R_{E,T}$ VERSUS ΔP BY ENSEMBLE

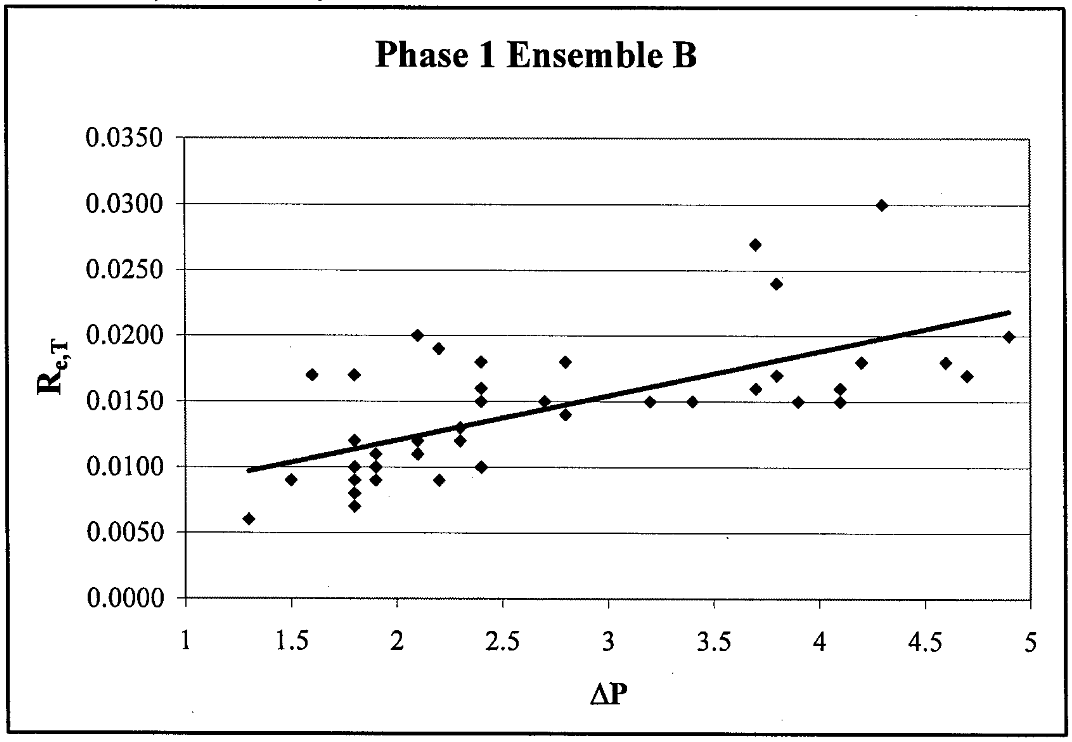
Appendix H

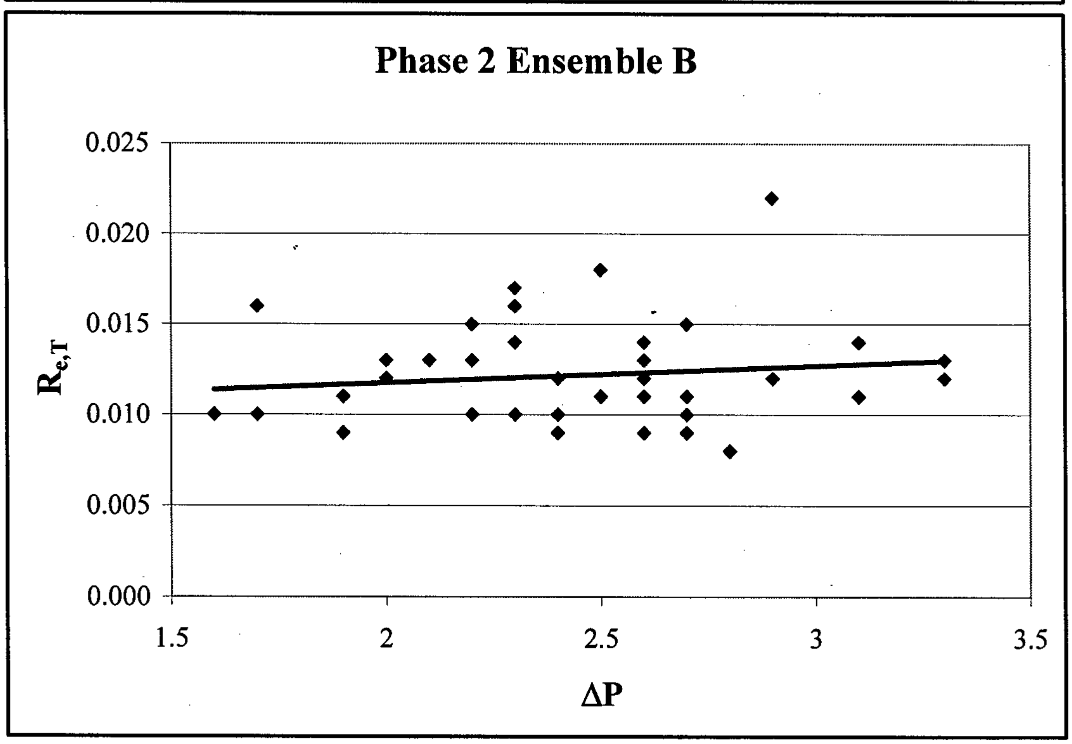
Graphs of $R_{e,T}$ versus ΔP by Ensemble



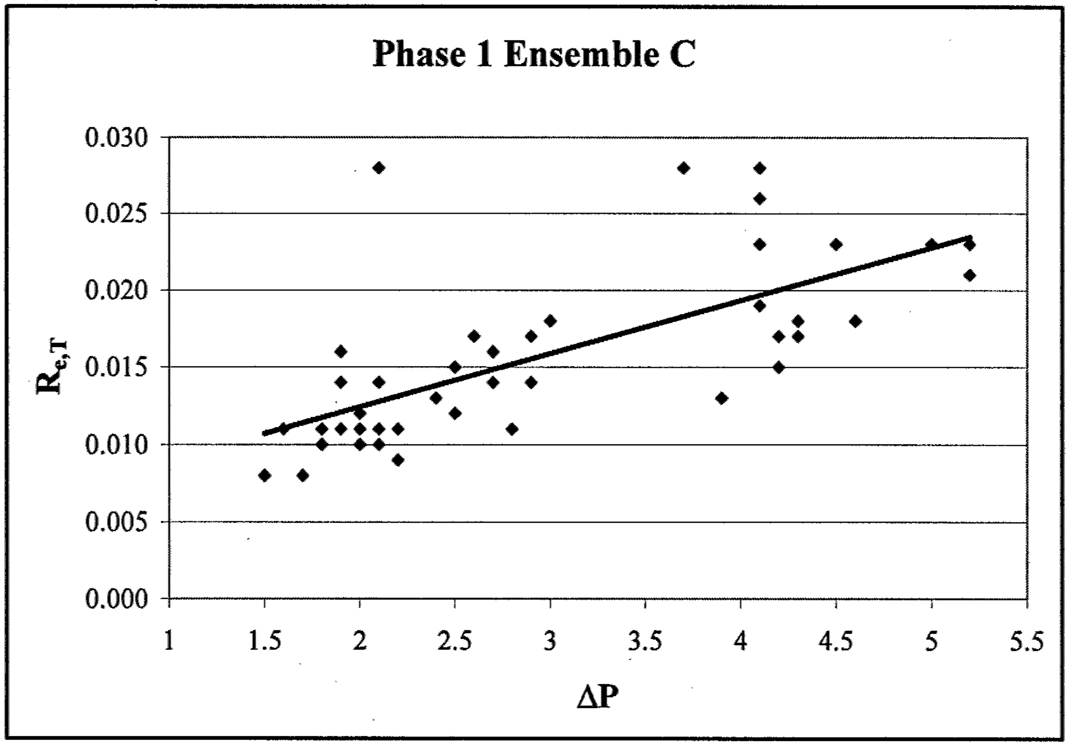


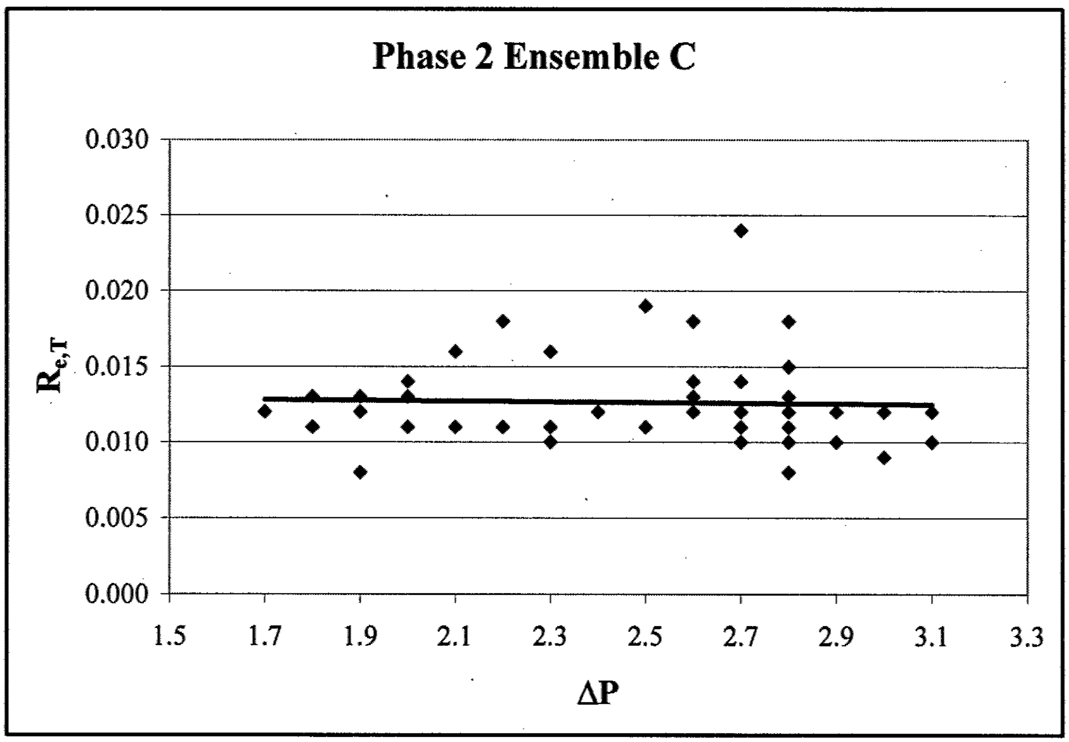
Graphs of $R_{e,T}$ versus ΔP by Ensemble



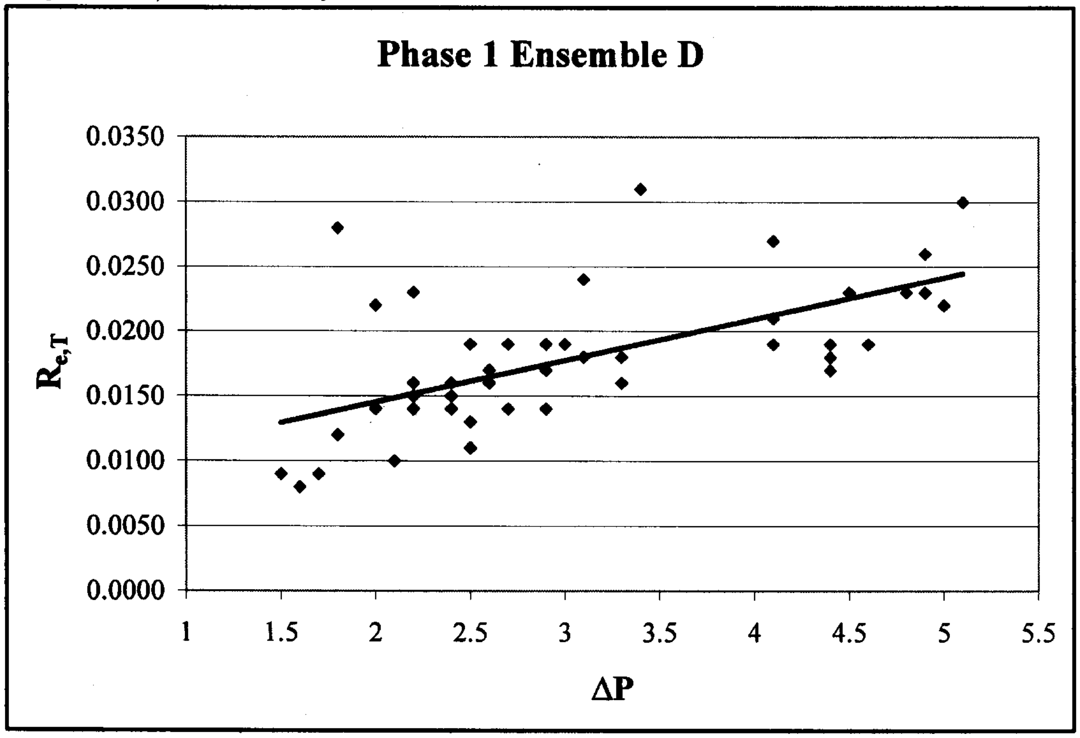


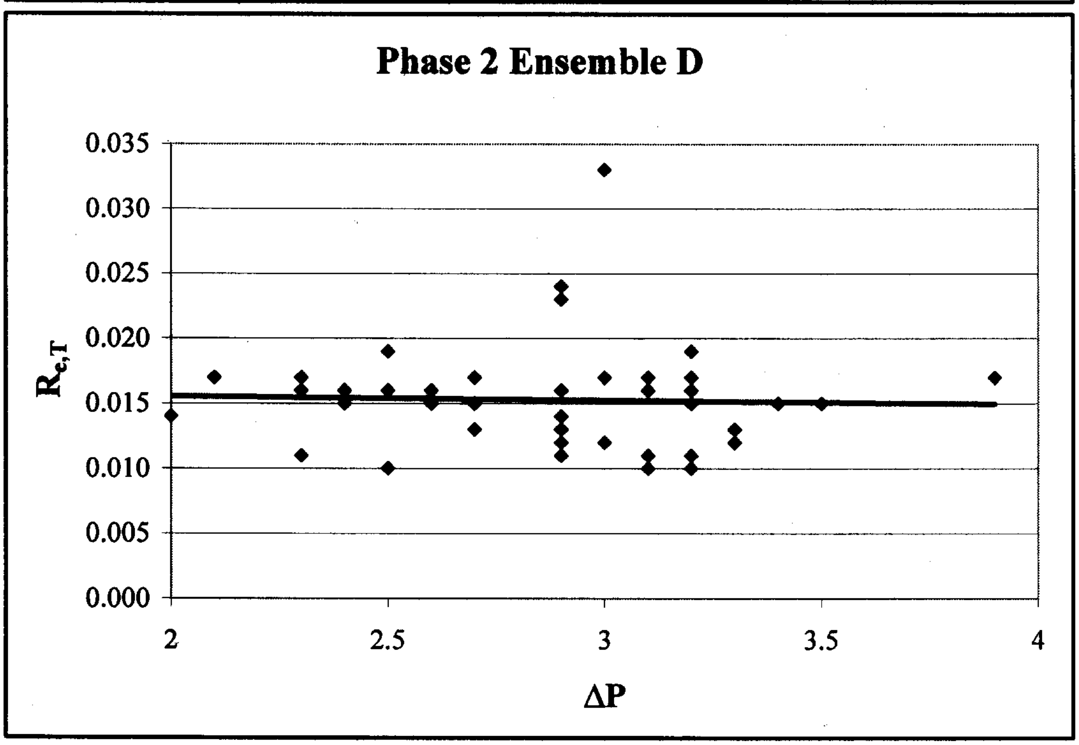
Graphs of $R_{e,T}$ versus ΔP by Ensemble



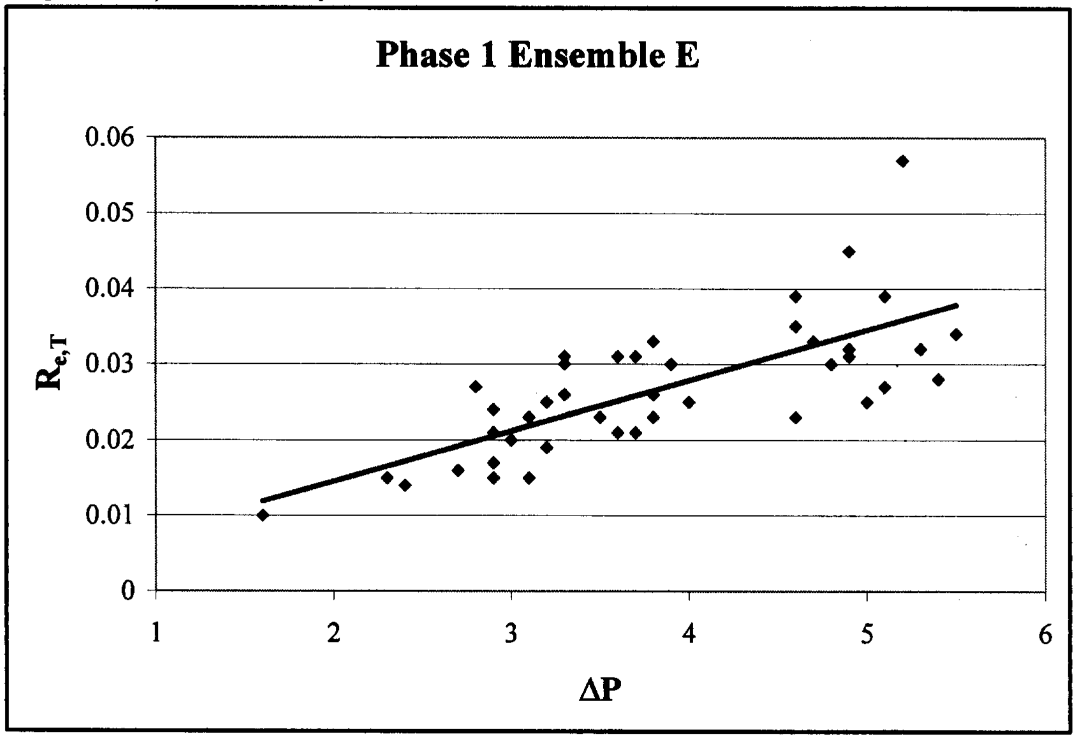


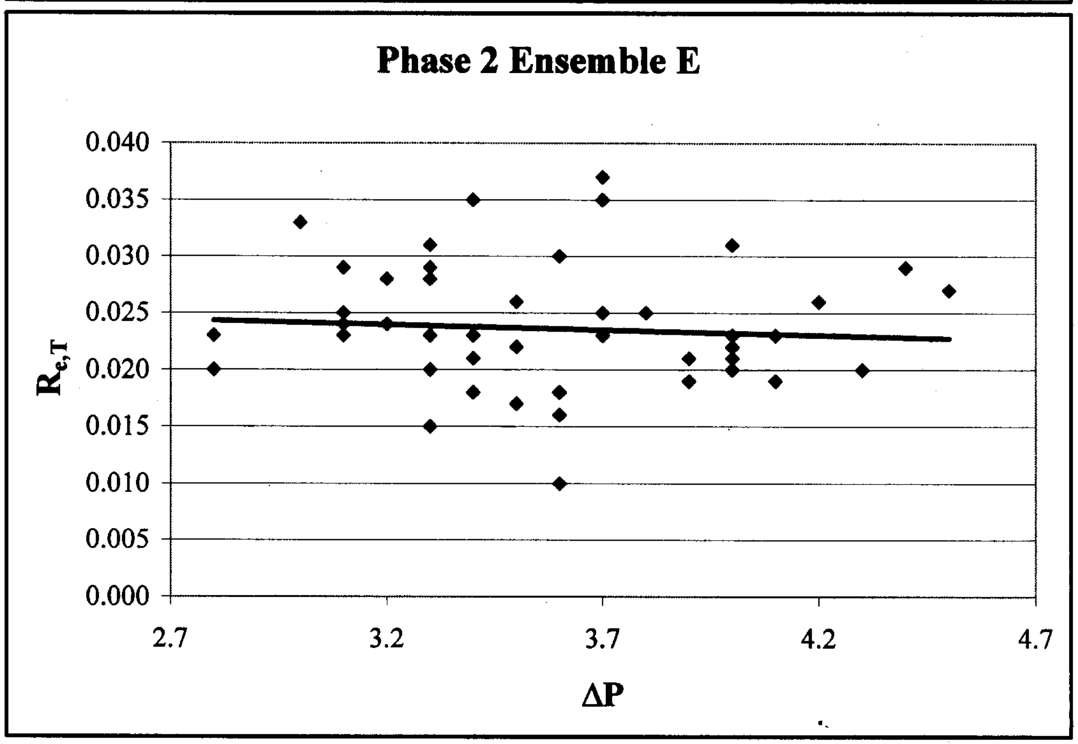
Graphs of $R_{e,T}$ versus ΔP by Ensemble





Graphs of $R_{e,T}$ versus ΔP by Ensemble





ABOUT THE AUTHOR

Major Victor Caravello received a Bachelor's Degree in Industrial Technology from Binghamton University in 1989. He was commissioned a 2nd Lieutenant in the United States Air Force in 1990 and began his career in the military as a bioenvironmental engineer. He completed a M.S. in Toxicology from Texas A&M University in 1998. He has published technical reports dealing with human health risk assessments. He entered the Ph.D. program in occupational and environmental health at the University of South Florida in 2001.

While at the University of South Florida, Major Caravello did research in the Heat Stress Laboratory and served in various leadership positions within the student chapter of the Human Factors and Ergonomics Society. He has coauthored two publications in heat stress and presented three research papers at national level meetings – the American Industrial Hygiene Conference and Exposition and the American College of Sports Medicine Annual Meeting.